Systematic literature review on developing an integrated STEM leadership model for middle leaders in school

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ABSTRACT

This systematic literature review investigates the development of an integrated science, technology, engineering, and mathematics (STEM) leadership model tailored for middle leaders in Malaysian schools. The introduction highlights the global emphasis on STEM education to foster innovation and economic growth, while acknowledging Malaysia's commitment to enhancing STEM capabilities within its educational system. The problem statement identifies a gap in effective STEM leadership among middle leaders, which is critical for implementing STEM initiatives and improving student outcomes. To achieve this, we conducted an extensive search of scholarly articles from reputable databases such as Scopus and Web of Science (WoS), focusing on studies published between 2021 and 2024. The flow of study is based on PRISMA framework. The database found (n=34) final primary data was analyzed. The finding was divided into three themes which are i) STEM education policy and implementation; ii) leadership in STEM educational; iii) professional development in STEM education. The conclusion emphasizes the need for a specialized leadership model that incorporates instructional leadership principles, fosters professional development, and supports collaborative practices among middle leaders. This integrated model aims to address the unique challenges faced by middle leaders in Malaysian schools, ultimately enhancing STEM education and contributing to Malaysia's educational and economic aspirations.

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1. INTRODUCTION

In recent years, there has been a global shift towards prioritizing science, technology, engineering, and mathematics (STEM) education, driven by the recognition of its critical role in fostering innovation and economic growth. Malaysia, like many other countries, has embraced this paradigm shift, incorporating STEM into its educational policies and curricula. The Ministry of Education Malaysia (MOE) has implemented numerous initiatives aimed at enhancing STEM education at all levels, from primary to tertiary education. However, the success of these initiatives largely hinges on effective leadership, particularly at the middle management level in primary schools, where STEM foundations are laid. Middle leaders in Malaysian primary schools, including heads of departments and subject leaders, play a pivotal role in implementing and sustaining STEM initiatives [1]–[5]. These leaders are responsible for translating national policies into actionable plans, providing professional development for teachers, and fostering a collaborative culture that promotes STEM learning. However, the transition to a STEM-focused curriculum presents unique challenges that require a specific set of leadership competencies. Traditional leadership models often fall short in addressing these challenges, necessitating the development of a tailored leadership framework that integrates STEM-specific competencies with general leadership skills. The need for an integrated STEM leadership model for middle leaders in Malaysian primary schools is underscored by several factors. Firstly, middle leaders must possess a deep understanding of STEM disciplines to effectively guide and support teachers. This includes not only content knowledge but also familiarity with pedagogical strategies that promote inquiry-based learning and critical thinking [6]–[8].

Secondly, they need strong management skills to coordinate resources, manage budgets, and ensure the availability of appropriate teaching materials and infrastructure. Additionally, middle leaders must be adept at fostering partnerships with external stakeholders, such as industry experts and higher education institutions, to enrich the STEM learning experience [9], [10]. Recent studies have highlighted the critical competencies required for effective leadership in the context of STEM education. For instance, professional leadership competencies for middle leaders include strategic planning, instructional leadership, and the ability to create a supportive learning environment [11], [12]. Furthermore, the concept of servant leadership, which emphasizes serving others and focusing on the growth and well-being of people and communities, has been identified as particularly relevant in the Malaysian educational context [13]–[15]. This approach aligns well with the collaborative and supportive nature required to foster effective STEM education. Despite the recognition of these competencies, there remains a gap in the practical application and integration of these skills into a cohesive leadership model. This gap highlights the necessity for a comprehensive framework that not only outlines the required competencies but also provides practical guidelines for their implementation.

Such a framework would serve as a valuable tool for professional development, equipping middle leaders with the skills needed to effectively lead STEM initiatives and ultimately enhance STEM education outcomes in Malaysian primary schools. In conclusion, developing an integrated STEM leadership model for middle leaders in Malaysian primary schools is a critical step towards realizing the country's educational and economic goals. By equipping these leaders with the necessary competencies and providing a clear framework for action, Malaysia can ensure the successful implementation of STEM initiatives, thereby fostering a new generation of innovators and problem solvers. This article aims to explore the key components of such a model, drawing on current research and best practices to provide a comprehensive guide for middle leaders in the Malaysian education system.

2. LITERATURE REVIEW

Developing an integrated STEM leadership model for middle leaders in Malaysian schools requires an in-depth understanding of various successful strategies and programs globally. The literature indicates that effective leadership in STEM education involves equipping educators with the necessary skills and knowledge to foster STEM talent and create conducive learning environments. Lakin *et al.* [16] highlights the importance of teacher professional development in rural settings through the STEM Excellence and Leadership project. This project equips teachers in grades 5-8 with the skills needed to identify and nurture STEM talent, which is crucial for middle leaders who aim to cultivate a robust STEM culture within their schools. Similarly, Ferrara *et al.* [17] discuss the benefits of engaging undergraduate STEM majors in outreach activities, which can serve as a model for middle leaders to implement extracurricular STEM clubs in schools. These initiatives help to enhance students' interest and engagement in STEM subjects, providing them with practical experiences that complement their academic learning. Incorporating insights from diverse educational contexts can further inform the development of a STEM leadership model. Sellami *et al.* [18] examine the factors influencing student interest in STEM in Qatar, revealing that gender, nationality, and parental education significantly impact students' decisions to pursue STEM careers. This highlights the need for middle leaders to consider these socio-cultural factors when developing STEM programs and policies. Additionally, the findings on gender differences in STEM leadership aspirations underscore the importance of creating an inclusive environment that encourages both male and female students to pursue leadership roles in STEM fields [19].

Research by Sun [20] explores the role of teacher leadership in implementing STEAM problem-based learning (PBL), emphasizing the need for continuous professional development and effective professional learning communities. Middle leaders can adopt these practices to foster a collaborative culture among teachers, enhancing the overall quality of STEM education. Antoshchuk [21] provides a comprehensive review of gender inequality in engineering in Russia, suggesting that middle leaders should address gender disparities and create supportive environments for female students in STEM. Programs like the youth enjoy science (YES) program described by Qua *et al.* [22] offer valuable insights into increasing engagement and opportunities for underrepresented minority students. Middle leaders can implement similar initiatives to provide mentorship and hands-on research experiences, thereby fostering a diverse and inclusive STEM community. Study by Weinstein [23] also emphasizes the importance of vocational training and mentoring, suggesting that integrating these elements into the school curriculum can better prepare students for STEM careers.

In summary, developing an integrated STEM leadership model for middle leaders in Malaysian schools should incorporate professional development, outreach activities, socio-cultural considerations, gender inclusivity, collaborative teacher leadership, and mentorship programs. These elements collectively create a supportive and enriching environment for STEM education, ensuring that students are well-equipped to pursue STEM careers.

Developing an integrated STEM leadership model for middle leaders in Malaysian schools requires a comprehensive understanding of various factors influencing STEM education and leadership practices. Research by Martin *et al.* [24] emphasizes that high levels of innovation among science teacher leaders correlate with their use of effectual reasoning, which involves viewing uncertainty positively and managing innovation risks effectively. This approach promotes deeper content understanding and reform-oriented pedagogies in STEM education. Moreover, Liu *et al.* [25] developed a predictive model using students' behavioral data to forecast their potential entry into STEM careers, demonstrating the importance of early career planning and the role of educational tools in fostering future STEM leaders. Additionally, Yanay-Ventura *et al.* [26] discuss the motivations and benefits of civic service among minority groups, which, while focused on a different context, highlights the importance of resource accumulation and high school achievement in educational leadership. Leadership practices in diverse educational settings also provide insights into effective STEM leadership. Murphy [27] identifies key practices in rural Australian schools that contribute to STEM success, such as leveraging community relationships, utilizing local resources, empowering teaching staff, and promoting the value of STEM education. These practices can be adapted to Malaysian schools to enhance STEM leadership. Similarly, Hendrickson *et al.* [28] explore caring-oriented leadership in Historically Black Colleges and Universities (HBCUs), highlighting the role of multidimensional caring in STEM academic leadership. This perspective underscores the importance of a supportive and inclusive leadership approach that can be beneficial in the Malaysian context.

The role identities and experiences of women in STEM leadership also offer valuable lessons for developing a comprehensive leadership model. Qadhi *et al.* [29] examine the challenges faced by female middle management leaders in Qatari universities, emphasizing the need for better support and formal leadership training. Their findings suggest that goal-oriented self-perception, collegial support, and family backing are crucial for successful leadership. Additionally, Hamdi *et al.* [30] discuss the importance of gender parity and diversity in STEM fields, advocating for equitable representation and leadership opportunities for women in science and engineering. This highlights the need for policies and practices that support gender equity in Malaysian schools. Furthermore, innovative educational models and leadership preparation programs contribute to the development of effective STEM leaders. Flores [31] describes the implementation of problem-based science (PbS) in a middle school setting, which fosters self-directed learning and higher engagement through student-driven, open-ended problem solving. This approach can be integrated into STEM leadership models to promote innovative teaching practices. Christensen and Knezek [32] developed the innovation attitude survey to measure middle school students' attitudes toward innovation and leadership, providing valuable insights into the dispositions that may influence future STEM careers. Such tools can be utilized to assess and enhance the leadership potential of middle leaders in Malaysian schools.

Effective professional development and capacity building are essential for sustaining STEM education initiatives. Borko *et al.* [33] discuss the role of video-based discussions in preparing professional development leaders, emphasizing the need for models that address district priorities and support instructional leadership. This approach can be adapted to Malaysian schools to build the capacity of middle leaders and ensure the successful implementation of STEM curricula. Wieselman *et al.* [34] highlight the importance of leadership, reform-based instructional strategies, and professional learning in developing a district-wide STEM education vision. These elements are crucial for creating a cohesive and sustainable STEM leadership model. In conclusion, developing an integrated STEM leadership model for middle leaders in Malaysian schools involves drawing on diverse research findings and best practices. Emphasizing entrepreneurial thinking, care-oriented leadership, gender equity, innovative teaching models, and effective professional development can create a robust framework for enhancing STEM education. By adapting these insights to the Malaysian context, middle leaders can be empowered to drive meaningful and sustainable improvements in STEM education.

The integration of STEM leadership models in Malaysian schools emphasizes the necessity of middle leaders who can navigate the complexities of modern educational demands. Nozaleda and Calubaquib [35] identified a significant gap between the perceived and actual integration of research in teaching within the Philippines' STEM education context. This discrepancy underscores the need for strong leadership to foster a culture where research and teaching coalesce seamlessly. The study advocates for the development of creative and critical thinking dispositions among educators, a critical component that can be extended to Malaysian middle leaders to enhance their effectiveness in implementing STEM curricula. Similarly, Sumarni *et al.* [36] demonstrated the effectiveness of the RE-STEM App in improving students' scientific literacy in Indonesia, employing ethno-STEM learning. This approach, which integrates local cultural elements into STEM education, highlights the importance of contextual relevance in teaching methodologies. For middle leaders in

Malaysia, adopting similar innovative tools and techniques could lead to improved student outcomes by making STEM education more engaging and relatable. This ethnoscience aspect can be an integral part of a leadership model that encourages teachers to incorporate cultural contexts into their teaching strategies, thereby enhancing scientific literacy.

The importance of leadership in STEM education is further supported by Martin *et al.* [24], who emphasized the role of effectual reasoning in entrepreneurial science teacher leaders. Their study found that innovation among these leaders is closely linked to their ability to manage uncertainties and embrace reform-oriented pedagogies. Middle leaders in Malaysia can benefit from adopting these entrepreneurial traits, encouraging a school culture that is adaptable, forward-thinking, and supportive of continuous innovation in STEM education. This aligns with the need for professional development that prepares leaders to foster such an environment. Moreover, the findings of Wieselman *et al.* [34] stress the significance of leadership in developing a district-wide vision for STEM education. Effective middle leaders must be able to articulate and implement a cohesive strategy that aligns with broader educational goals. This includes promoting professional learning communities where best practices in STEM education are shared and refined. Murphy [27] further supports this by identifying successful leadership practices in rural Australian schools, such as leveraging community resources and empowering teaching staff, which can be adapted to the Malaysian context to build a robust STEM leadership framework.

Additionally, the role identities of female middle management leaders in STEM, as explored by Qadhi *et al.* [29] highlight the importance of gender parity in leadership roles. Ensuring diverse representation in STEM leadership not only promotes equity but also brings a variety of perspectives and solutions to educational challenges. Middle leaders in Malaysia should therefore advocate for and support policies that encourage gender diversity and provide opportunities for women to excel in STEM leadership roles. In conclusion, developing an integrated STEM leadership model for middle leaders in Malaysian schools involves synthesizing various insights from global research. Emphasizing the integration of research in teaching, employing innovative and culturally relevant teaching tools, adopting entrepreneurial leadership traits, articulating a clear STEM vision, and promoting gender diversity are critical components. These elements collectively form a comprehensive framework that can enhance the effectiveness of middle leaders and improve STEM education outcomes in Malaysian schools.

3. METHOD

The elucidation of the preferred reporting items for systematic reviews and meta-analyses (PRISMA) publication standard is provided by the authors in the introductory part of this section. Upon this, the authors delve into an extensive discussion on the process of formulating research inquiries, expounding on the meticulous systematic searching methodologies employed which encompass identification, screening, and eligibility criteria. Moreover, they elaborate on the procedures for assessing the quality of the studies included, as well as delineate the methodologies for extracting and analyzing data in a comprehensive manner.

3.1. Identification

A considerable number of relevant publications were chosen for this investigation by using many crucial elements of the systematic review procedure. Following the initial selection of keywords, dictionaries, thesauri, encyclopedias, and prior research were searched for relevant terms. Search strings were created for the Web of Science (WoS) and Scopus databases, and all pertinent terms were found as shown in Table 1. These three databases yielded 496 papers that were found to be pertinent to the study issue during the first phase of the systematic review.

3.2. Screening

During the screening phase, the gathered research items are reviewed to ensure they match the predefined research questions. This phase includes selecting items focused on developing an integrated STEM leadership model for middle leaders in Malaysian schools. At this stage, duplicate papers are removed. Initially, 296 publications were excluded, and subsequently, 99 papers were assessed using specific inclusion and exclusion criteria for this study as presented in Table 2. The main criterion was research literature, as it provides practical recommendations. This also included reviews, meta-syntheses, meta-analyses, books, book series, chapters, and conference proceedings not covered in the latest study. The review was limited to English publications from 2021-2024. A total of 32 publications were discarded due to duplication.

3.3. Eligibility

In the third phase, referred to as the eligibility assessment, a compilation of 67 articles was assembled. During this stage, a meticulous examination of the titles and core content of all the articles was conducted to confirm their alignment with the inclusion criteria and their relevance to the ongoing study's research objectives. Consequently, 33 data/paper/article were excluded as they did not qualify as due to the out of field, title not significantly, abstract not related on the objective of the study and no full text access founded on empirical evidence. As a result, a total of 34 articles remains for the upcoming review.

Table 1. The search string used for the systematic review process

Source	Search string
Scopus	TITLE-ABS-KEY ((leader* AND "STEM education*")) AND (LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "PHYS") OR LIMIT-TO (SUBJAREA , "MATH") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "PSYC") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "ARTS") OR LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "BIOC") OR LIMIT-TO (SUBJAREA , "MULT") OR LIMIT-TO (SUBJAREA , "CHEM") OR LIMIT-TO (SUBJAREA , "CENG") OR LIMIT-TO (SUBJAREA , "NEUR")) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024)) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final")) Date of access: June 2024
WoS	leader* AND "stem education*" (Topic) and Article (Document Types) and English (Languages) and 2021 or 2022 or 2023 or 2024 (Publication Years) and Article (Document Types) and Science Technology Other Topics or Environmental Sciences Ecology or Engineering or Education Educational Research or Social Sciences Other Topics or Chemistry or Mathematics (Research Areas) Date of access: June 2024

Table 2. The inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2021–2024	<2021
Literature type	Journal (article)	Book, review, conference
Publication stage	Final	In press
Subject	Social sciences, computer science, engineering, psychology, mathematics, multidisciplinary, chemical engineering, chemistry, biochemistry genetics and molecular biology, arts and humanities, environmental science, neuroscience, energy, earth and planetary, physics and astronomy and business, management and accounting.	Besides social sciences, computer science, engineering, psychology, mathematics, multidisciplinary, chemical engineering, chemistry, biochemistry genetics and molecular biology, arts and humanities, environmental science, neuroscience, energy, earth and planetary, physics and astronomy and business, management and accounting.

3.4. Data abstraction and analysis

The study employed integrative analysis as a key assessment strategy to review and synthesize various quantitative research designs. The study aimed to identify pertinent topics and subtopics, beginning with data collection to develop themes. Figure 1 illustrates the thorough analysis of 34 publications for relevant content. The authors reviewed significant studies on developing an integrated STEM leadership model for middle leaders in Malaysian schools, investigating the methodologies and results of these studies. Collaborating with co-authors, they developed themes based on the gathered evidence. Throughout data analysis, a log was maintained to document analyses, viewpoints, puzzles, and other thoughts related to data interpretation. Finally, the authors compared their findings to check for inconsistencies in theme development and resolved any conceptual disagreements through discussion.

The authors also compared the findings to resolve any discrepancies in the theme creation process. Note that if any inconsistencies on the themes arose, the authors address them with one another. Finally, the developed themes were tweaked to ensure their consistency. To ensure the validity of the problems, the examinations were performed by two experts, specializing in leadership and STEM education. The expert review phase helped ensure each sub-theme’s clarity, importance, and adequacy by establishing domain validity. Adjustments based on the discretion of the author based on feedback and comments by experts have been made. The questions are:

i) How do various stakeholders perceive and implement STEM education policies and programs, and what challenges and opportunities do they encounter?
ii) What are the key attributes and practices of effective leadership in STEM education, and how do they contribute to the success of STEM initiatives?
iii) What are the effective strategies for providing professional development to educators in STEM fields, and how do they impact teaching and learning outcomes?

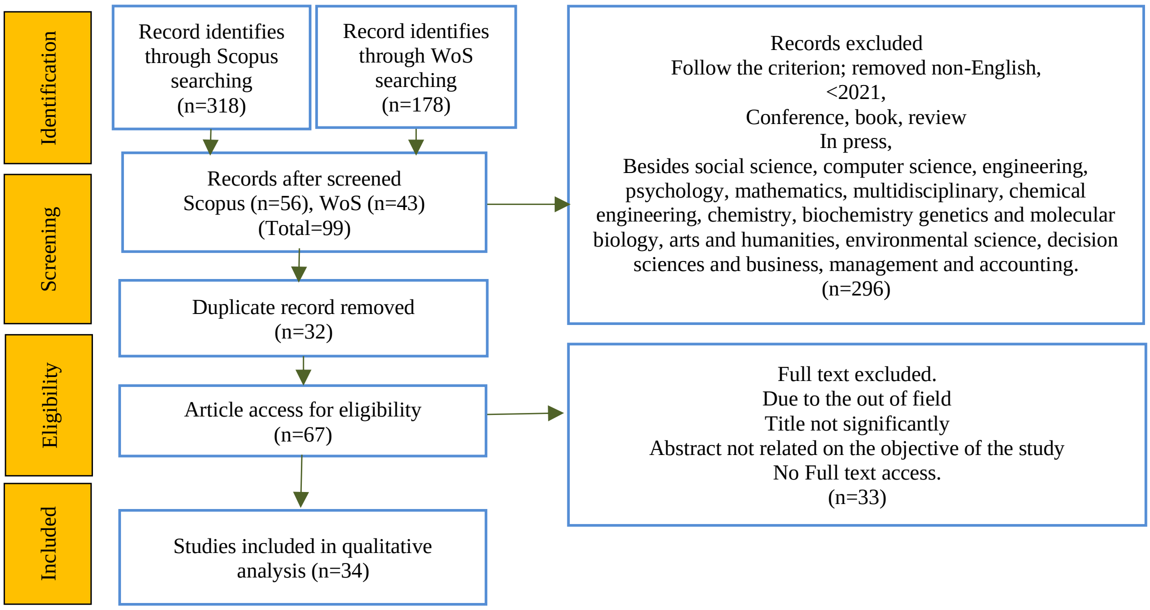

Figure 1. Flow diagram of the proposed searching study [37]

4. RESULTS AND DISCUSSION

The examination led to the discovery of three primary themes associated with the formulation of a comprehensive STEM leadership framework tailored for middle-level leaders within educational institutions. These three core themes encompassed the areas of “STEM Education Policy and Implementation”, “Leadership in STEM Education”, and “Professional Development in STEM Education”. The synthesis of these three principal themes derived from the analysis of 34 scholarly articles included in this study has been succinctly outlined and presented in Table 3 [27], [28], [32], [34], [38]–[67].

In examining the development of an integrated STEM leadership model for middle leaders in schools, three critical themes emerged from the findings: STEM education policy and implementation, leadership in STEM education, and professional development. The alignment of STEM education policies with practical implementation strategies is essential for fostering a conducive environment for STEM learning. Effective leadership in STEM education plays a pivotal role in guiding these initiatives, while continuous professional development ensures that middle leaders are equipped with the necessary skills and knowledge to drive sustainable STEM education practices. The subsequent discussion enables concluding.

4.1. Theme 1: STEM education policy and implementation

STEM education policy and implementation involve complex interactions among various stakeholders, curriculum design, professional learning, leadership, and school culture. Research by Falloon *et al.* [44] emphasizes the pivotal role of school leaders in communicating a clear vision for STEM, which builds trust and commitment among staff, mitigating challenges such as rigid curriculum structures. Similarly, Thingwiangthong *et al.* [45] highlight the need for STEM curriculum development to be contextually relevant and collaboratively designed by teachers to address diverse student needs, while Wu and Huang [39] underscore the importance of early childhood leaders' positive attitudes and institutional support for effective EC-STEM implementation. STEM program directors play a crucial role in broadening the impact of STEM interventions, as elucidated by Gomez *et al.* [43].

Their study explores strategies such as program efficacy demonstrations, coordination, incentivization, and support consolidation to drive STEM education transformation. Flanagan *et al.* [38] examine the challenges and opportunities of implementing Lesson Study in rural STEM education contexts, indicating its potential to foster collaboration and teacher reflection, though practical constraints hinder full engagement. Furthermore, the evolution of STEM education involves partnerships between industry, universities, and public schools, as demonstrated by Dieker *et al.* [46]. They discuss a long-standing partnership model preparing STEM teacher-leaders, highlighting its sustainability and program evolution over 30 years. Additionally, Santos [56] emphasizes the importance of second career-changing teachers with industry experience in addressing STEM workforce shortages, advocating for reforms in teacher training and professional development.

Moreover, district-wide STEM education visions require effective administrative leadership and stakeholder engagement, as evidenced by Wieselmann *et al.* [34]. Their study on a rural U.S. school district's

STEM transition underscores the critical components of leadership, instructional strategies, and teacher learning in achieving comprehensive STEM instruction. Finally, Santangelo *et al.* [48] propose the (STEM)2 network as a model for transformative STEM higher education, focusing on empowering faculty and fostering collaboration across disciplines and institutions to address workforce challenges and promote inclusive STEM pathways. These studies collectively highlight the multifaceted nature of STEM education policy and implementation, emphasizing the importance of leadership, collaboration, contextual relevance, and stakeholder engagement in driving effective STEM education initiatives.

4.2. Theme 2: leadership in STEM education

Leadership in STEM education is essential for fostering positive learning cultures and promoting innovation within educational institutions. According to a model developed by Geiger *et al.* [49], effective STEM leadership involves five dimensions: STEM discipline-specific and integrated knowledge and practices, contexts, dispositions, tools, and critical orientation. This model emphasizes the importance of principals possessing a deep understanding of STEM disciplines, integrating STEM into various contexts, fostering positive dispositions towards STEM, utilizing appropriate tools, and maintaining a critical perspective on STEM education. Murphy [27] highlights the significance of leadership practices in shaping STEM education success, particularly in rural schools. Leadership practices such as leveraging community relationships, utilizing local resources, empowering STEM teaching staff, promoting the value of STEM education, and supporting STEM pathways contribute significantly to the success of STEM education initiatives.

Moreover, Velasco *et al.* [51] explore advocacy self-efficacy among K-12 STEM teacher leaders. Their study underscores the importance of professional development programs focusing on policy knowledge and advocacy activities to develop and sustain STEM teacher leaders' advocacy self-efficacy. Participation in such programs provides opportunities for mastery experiences in STEM education advocacy. Furthermore, Hendrickson *et al.* [28] examine caring-oriented STEM academic leadership from the perspective of academic management at historically HBCUs.

The study identifies evidence of multidimensional caring in STEM-related academic managerial leadership, highlighting the importance of caring-oriented leadership practices in fostering a supportive STEM education environment. In summary, effective leadership in STEM education requires principals and academic managers to possess deep disciplinary knowledge, integrate STEM into various contexts, empower stakeholders, advocate for STEM education, and foster a supportive learning environment. These leadership practices play a crucial role in promoting STEM education success and cultivating a culture of innovation and excellence in educational institutions.

4.3. Theme 3: professional development in STEM education

Professional development in STEM education encompasses a multifaceted approach to enhancing the skills and knowledge of educators and practitioners within the field. Velychko *et al.* [60] emphasize the importance of training practicing teachers to effectively implement STEM education, underscoring the role of practitioners as leaders in high-tech changes within the educational system. Their study highlights the need for professional development programs that are scientifically sound, encourage interdisciplinary interaction, and introduce innovative teaching methods. Similarly, Maashi *et al.* [61] address the necessity of sustainable professional development for STEM teachers, particularly in Saudi Arabia, within the context of international standards and the country's vision 2030. They identify obstacles to sustainable professional development methods and propose strategies for overcoming these challenges, emphasizing the importance of ongoing teacher training to meet evolving educational demands.

Furthermore, Hite and Milbourne [62] examine the professional development experiences of K-12 STEM master teacher leaders in the United States. Through an interpretive phenomenological approach, they explore the lived experiences of nationally recognized STEM teacher leaders and identify key themes such as the significance of school culture, access to professional networks, and personal motivation. This underscores the importance of cohesive professional development systems to recruit, develop, and retain master teachers and teacher leaders in STEM. Agarwal *et al.* [63] contribute to the discussion by addressing the effectiveness of teaching development programs for engineering graduate students, highlighting the lack of structured evaluations and frameworks for assessing program success. Their study underscores the need for evidence-based evaluation methods to measure the impact of professional development programs accurately. Moreover, Bering *et al.* [64] discuss the Undergraduate Student Instrumentation Project (USIP) as an effective model for delivering STEM education and fostering student engagement in space research. Their project-based approach, rooted in the 5E instructional model, emphasizes student-centered learning and interdisciplinary collaboration. This highlights the importance of hands-on experiences and collaborative projects in professional development initiatives within STEM education.

Finally, Sunny and Koenig [65] advocate for a community-based participatory mixed methods methodology, such as concept mapping, to develop innovative scales for assessing attitudes and persistence in STEM education. Their research underscores the value of involving diverse stakeholders in the research process to ensure the relevance and effectiveness of professional development tools and strategies. In conclusion, professional development in STEM education plays a crucial role in equipping educators and practitioners with the necessary skills, knowledge, and resources to excel in their fields. By addressing challenges, fostering collaboration, and implementing innovative approaches, stakeholders can ensure the continued growth and success of STEM education initiatives.

Table 3. A simplified table of studies included in the systematic review

Theme	No.	Study	Year
Theme 1: STEM education policy and implementation	1	[38]	2024
	2	[39]	2023
	3	[40]	2022
	4	[41]	2022
	5	[42]	2022
	6	[43]	2021
	7	[44]	2021
	8	[45]	2021
	9	[46]	2021
	10	[47]	2021
	11	[34]	2021
	12	[48]	2021
Theme 2: leadership in STEM education	1	[49]	2023
	2	[27]	2023
	3	[50]	2023
	4	[51]	2022
	5	[52]	2022
	6	[53]	2022
	7	[28]	2021
	8	[54]	2021
	9	[55]	2021
	10	[56]	2021
Theme 3: professional development in STEM education	1	[57]	2023
	2	[58]	2023
	3	[59]	2022
	4	[60]	2022
	5	[61]	2022
	6	[62]	2022
	7	[63]	2022
	8	[32]	2022
	9	[64]	2021
	10	[65]	2021
	11	[66]	2021
	12	[67]	2021

5. CONCLUSION

In summary, these studies collectively highlight the multifaceted nature of STEM education policy and implementation, emphasizing the importance of leadership, collaboration, contextual relevance, and stakeholder engagement in driving effective STEM education initiatives. Effective leadership in STEM education requires principals and academic managers to possess deep disciplinary knowledge, integrate STEM into various contexts, empower stakeholders, advocate for STEM education, and foster a supportive learning environment. These leadership practices play a crucial role in promoting STEM education success and cultivating a culture of innovation and excellence in educational institutions. Professional development in STEM education plays a crucial role in equipping educators and practitioners with the necessary skills, knowledge, and resources to excel in their fields. By addressing challenges, fostering collaboration, and implementing innovative approaches, stakeholders can ensure the continued growth and success of STEM education initiatives.

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