VTE VOCATION, TECHNOLOGY & EDUCATION

REVIEW ARTICLE

Integration between STEM education and TVET in Malaysia: A systematic literature review and thematic bibliometric analysis

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Abstract

Amid globalization and the rapid development of information technology, science, technology, engineering, and mathematics (STEM) education has become central to developing the competencies required for innovation, national competitiveness, and readiness for Industry 4.0. In Malaysia, STEM initiatives have expanded significantly over the past decade, but their alignment with the transformation agenda for technical and vocational education and training (TVET) remains underexamined. This gap was addressed in the current study through a systematic literature review of 116 Scopus-indexed articles to synthesize major research themes, methodological trends, and structural challenges in Malaysia's STEM education landscape. As a complement to the review, a thematic bibliometric analysis was performed using VOSviewer. The findings indicated notable progress in curriculum reform, technology-enhanced learning, and teacher professional development. Nevertheless, persistent issues that include disparities in resource distribution, inconsistent pedagogical quality, and declining student interest continue to undermine national STEM outcomes. Importantly, the analysis revealed limited integration between STEM education research and TVET workforce priorities, with insufficient focus directed toward technical readiness, employability competencies, and pathways to vocational and technical careers. This review provides a conceptual basis for strengthening the STEM-TVET pipeline and offers evidence-based recommendations for policymakers and researchers seeking to align STEM education with emerging demands for national and global skills.

Keywords

science, technology, engineering, and mathematics education, technical and vocational education and training integration, systematic literature review, bibliometric, interdisciplinary, workforce development

INTRODUCTION

The rapid advancement of digital technologies and the emergence of the Fourth Industrial Revolution (Industry 4.0) have intensified global demand for a highly skilled workforce capable of creativity, problem-solving, and technological adaptability. Therefore, STEM education—which encompasses science, technology, engineering, and mathematics—has become a critical pillar of national development strategies worldwide (Le *et al*., 2022). In Malaysia, STEM is not only positioned as a catalyst for enhancing scientific literacy and student competencies but also increasingly recognized as a foundational component of the country's transformation agenda for technical and vocational education and training (TVET). These developments have given rise to the essential goal of understanding how STEM education supports or constrains pathways to securing employment in TVET and successfully participating in

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industry. These issues have also elicited increasing attention at the policy level. However, current academic research is lacking in terms of the overall analysis of Malaysia's STEM development and its alignment with the priorities of TVET in the country.

Since the advent of the 21st century, humanity has considerably advanced with respect to technologies such as artificial intelligence, big data, cloud computing, and the Internet of Things, among other domains (Dai *et al*., 2023; Paul *et al*., 2020). Nevertheless, there remains a substantial gap in fulfilling employers' demand for 21st century talents, especially those proficient in STEM given that education in the domains of science, technology, engineering, and mathematics offers students the opportunity to master the competencies required by contemporary workplaces and the ability to cope with Industry 4.0 (van Laar *et al*., 2017; Wahono *et al*., 2020). STEM education has had a long history, and after decades of development, its importance in talent training and national advancement has been recognized by an increasing number of countries and regions (Bybee, 2010, 2013). STEM education has also proved helpful in cultivating complex problem-solving skills and has exerted positive effects on students' overall career development, thus prompting the progressive development of STEM-centered learning practices (Yip & Chan, 2019). STEM education plays a key role in the development of the talents and skills necessary for the 21st century (Clark *et al*., 2021; Kelley & Knowles, 2016).

Meanwhile, recent years have witnessed new technologies and global events exert influence on STEM development (Gomoll *et al*., 2018), compelling many countries to elevate STEM education to the level of a national strategy (Simpson & Bouhafa, 2020; Wahono & Chang, 2019). The enactment of legislation on STEM has also considerably stimulated the expansion of STEM-related fields, as is the case in the United States, China, the United Kingdom, Australia, and Japan, among other nations (Simpson & Bouhafa, 2020; Wahono & Chang, 2019). Numerous countries have formulated STEM development strategies and delivered STEM education to various school sectors, from early childhood to K-12 education, postsecondary to adult education, and lifelong learning institutions (Leung, 2020; Li *et al*., 2020; Roehrig *et al*., 2021). Such initiatives advocate for the combination of new technologies and new industrial structures for STEM education (Leung, 2020; Li *et al*., 2020; Roehrig *et al*., 2021). These endeavors are intended to ensure improved alignment with labor force needs and requirements for industrial development in the 21st century, as well as guarantee the effective addressing of opportunities and challenges while STEM talents are cultivated (Anderson *et al*., 2020; Charania *et al*., 2021; Miller *et al*., 2021).

The same attention has been devoted to STEM education in Malaysia, which is a multiethnic and diverse Southeast Asian country whose economy has developed rapidly in recent years (Cuberes *et al*., 2023). The problem is that it is also confronted with issues such as unbalanced regional economic progress and poor alignment between TVET graduates' skills and market demands (Cuberes *et al*., 2023). These social problems have been addressed by the Malaysian government in different ways. In 2011, for example, the government established a TVET system to encourage public and private schools to cultivate STEM talents (Razali *et al*., 2022). In 2013, the Malaysian Education Blueprint (MEB) was issued by the Malaysian Ministry of Education (MOE), which regards STEM education as an important instrument of reform. The ministry implemented STEM transformation in three stages: The first stage (2013-2015) was intended to strengthen curriculum reform and provide appropriate teacher training. The second stage (2016-2020) was designed to refine curricula, raise public awareness of STEM, and enhance teaching skills and knowledge. The third stage (2021-2022) involved developing STEM-related know-how and expertise, with focus directed to innovation among students. Notwithstanding such advancements, student interest in STEM-related fields remains low, especially in middle school, and the STEM performance of learners is deficient (Idris *et al*., 2023). These shortcomings are compounded by the fact that Malaysian students lag considerably behind those of Singapore, China, and the United States in the mathematics and science domains of the Programme for International Student Assessment (PISA) (Zhu & Li, 2020). These realities have discouraged enrollment in STEM programs in higher education, thereby producing an insufficient number of STEM graduates who can support the development of the fields of science, technology, engineering, and mathematics (M. Z. Ismail *et al*., 2019). Data have shown that only 50.83% of Malaysian students choose to study STEM subjects, which falls short of the 60.00% target stipulated in national policy (Academy of Sciences Malaysia, 2018). This decline in interest and motivation for STEM learning has also occurred in other countries, such as the United States, Australia, and India (Kurniati *et al*., 2022).

The School Operations Sector of the Malaysian MOE explained that the ministry is actively taking measures to address the new challenges brought forth by the postpandemic era to the education system, to ensure the stable development of the national education landscape, and to facilitate the achievement of MEB objectives (Academy of Sciences Malaysia, 2021). For instance, to improve student interest in STEM education, the MOE has launched many programs designed to promote uptake. Examples include the Program Duta Guru, which is aimed at enhancing the teaching abilities of STEM educators, foster diverse learning methods, attract students to STEM programs, and so on (Malaysian Ministry of Education, 2024).

In 2023, the government invested approximately $100 million in the construction of digital education centers for TVET, which use digital technologies to empower teachers and improve teaching standards. It has conducted numerous market demand surveys and established many TVET programs not only to motivate students' selection of STEM-oriented jobs but also to strengthen exchange and cooperation with various industries (Razali *et al*., 2020). These efforts, however, do not negate certain realities, such as the difficulty of implementing STEM education in an interdisciplinary manner, the challenge of evaluating the results of such education, and the unbalanced development of educational resources (Zainal *et al*., 2018).

STEM education is increasingly linked to national TVET transformation. The 11th Malaysia Plan, Industry4WRD Policy, and the TVET Empowerment Agenda strongly emphasize strengthening STEM-TVET integration to produce a workforce adept at operating in high-technology contexts. Because STEM knowledge is foundational for vocational pathways such as engineering technology, digital manufacturing, automation, and computer systems, the alignment between STEM learning outcomes and TVET competencies has become a national priority in Malaysia.

Despite the abovementioned connections, there remains a lack of systematic reviews of how STEM education research in Malaysia corresponds with the employment goals of the TVET sector or to what extent STEM education fails to support TVET workforce goals. The current analysis, therefore, not only mapped trends in STEM scholarship but also identified their implications for Malaysia's ongoing TVET transformation. The hope is to provide solutions for countries facing the same social problems as those confronting Malaysia. To these ends, this study used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach to examining the literature and analyzed bibliometric visual data to explore the practical STEM education experiences of Malaysia, as discussed in high-quality academic articles recently published in Scopus-indexed journals. The key questions addressed were as follows: (1) What are the primary focus areas, educational levels, and thematic dimensions reflected in the trends characterizing STEM education research in Malaysia. (2) What are the challenges and strategic directions in STEM education in Malaysia, and how do these directions align with or deviate from global STEM trends.

METHODOLOGY

This study followed a rigorous systematic approach that began with a screening of the literature in accordance with the three-step PRISMA process (Figure 1): (1) Identifying the studies relevant to the current research, (2) using predetermined criteria to evaluate eligibility for inclusion, and (3) selecting the studies to be reviewed (Page *et al*., 2021).

Systematic literature review

Identification and initial screening

Scopus boasts broad inclusion coverage, covering a full range of disciplines such as science and engineering, humanities and social sciences, medicine and interdisciplinary fields, it includes diverse types of literature and covers academic publications from countries worldwide. Screening STEM-related literature from this database ensured the retrieval of articles encompassing all the four disciplines and enabled a preliminary evaluation based on keywords (*e.g.*, STEM keywords may trigger the appearance of unrelated topics such "stem cell."). Published articles that did not involve literature reviews were identified using their titles, abstracts, and keywords as reference. The Scopus database was then searched for research on STEM, STEAM, STEM education, or science education; technology education; engineering education; and mathematics education conducted in Malaysia, as our context of interest, from 2009 to 2024. This initial screening yielded a preliminary sample of 879 articles. Although the review focused on STEM education, the analysis also considered how the identified themes relate to Malaysia's national strategic priorities for TVET.

Exclusion

At this stage, we excluded (1) articles that were published beyond the period 2009 to 2024, (2) articles published in non-English journals, and (3) articles irrelevant to this review include off-topic literature concerning medical stem cells, steam engineering, the botanical definition of "stem", and papers with identical search terms but unrelated to STEM education. Relevance was determined by double-checking aspects including the titles, abstracts, keywords, and research methods.

Final sample

In this phase, three of professional researchers under education field were recruited, after confirming their participation, they were assigned independent data tasks. All the selected researchers carefully rechecked the original data and the collected literature, and then collectively excluded the studies with incomplete data and those not meeting the predetermined inclusion standard. This screening process was clearly documented to enhance the reproducibility of the method, while ensuring the completeness and internal

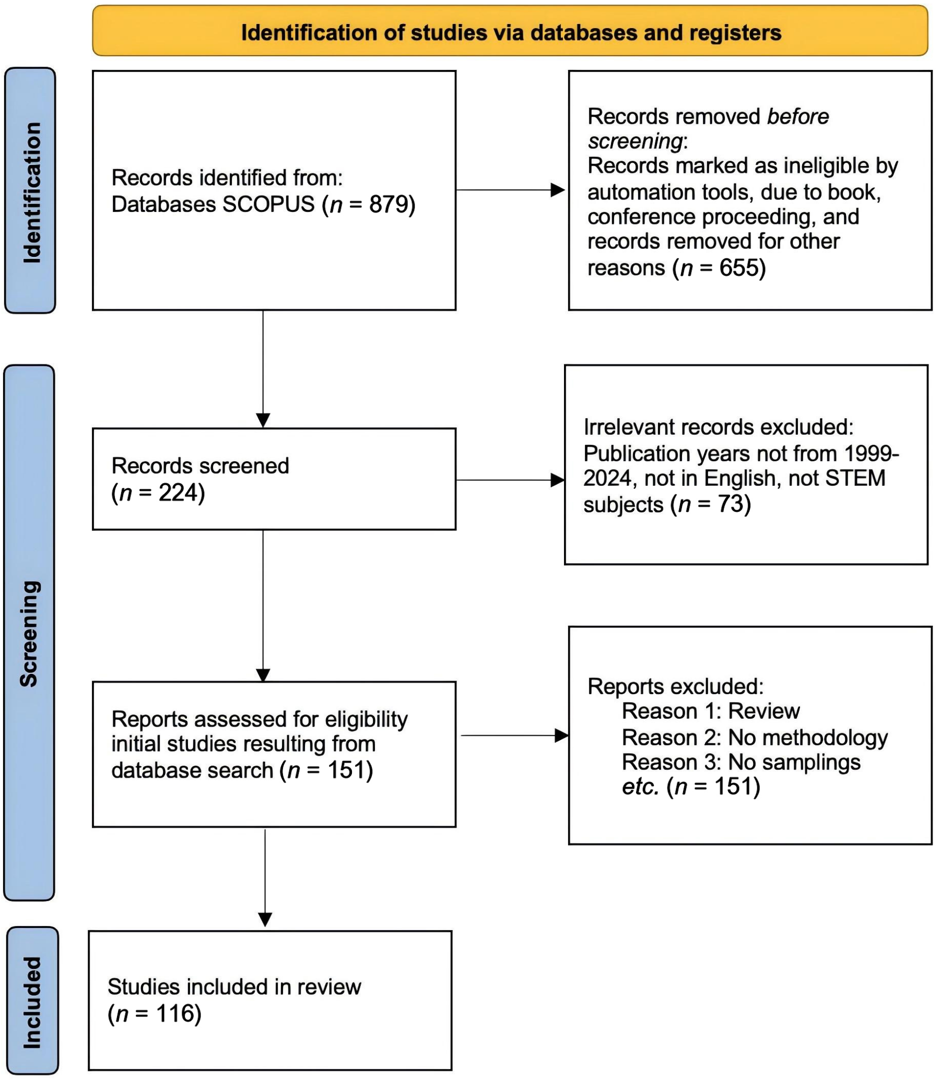

Figure 1. PRISMA flow chart: Identification of studies from the database. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

consistency of the final data.

As previously stated, the initial sample comprised 879 STEM-related articles, which were then screened to restrict selection to journals and articles published in English. This stage reduced the sample to 224, from which an additional 108 unrelated and review articles were eliminated. The analysis of relevance left us with a final sample of 116 articles for inclusion in the systematic review. These studies were investigated on the basis of their bearing on Malaysia's TVET priorities to establish an integrated framework for analyzing STEM-TVET integration in the country.

Thematic bibliometric analysis

To complement the systematic review and provide a structural overview of research development in STEM education in the Malaysian context, a bibliometric analysis was conducted using VOSviewer. Bibliometric mapping enables the identification of conceptual patterns, collaboration structures, and thematic evolution through a visualization of relationships among keywords, publications, and citations (van Eck & Waltman, 2014). This approach was particularly valuable for ascertaining how STEM education discourse aligns with TVET and workforce development priorities. The citation and bibliographic records retrieved from the Scopus database were exported in CSV format. Prior to analysis, the data were cleaned to ensure consistency.

Network construction in VOSviewer

The cleaned dataset was imported into VOSviewer using the full counting method, which assigns equal weight to all occurrences and is commonly employed in educational bibliometric studies (van Eck & Waltman, 2014). Three types of networks were generated: A keyword co-occurrence network designed to identify dominant research topics and emerging areas, a citation network meant to map the intellectual influence and distribution of foundational studies, and bibliographic coupling, which was intended to examine the thematic similarity between authors, institutions, and countries, particularly in relation to TVET-focused reforms. For keyword analysis, a minimum threshold of two occurrences was set to ensure that only meaningful and recurrent concepts were included in a given network.

Visualization and cluster interpretation
VOSviewer's network, overlay, and density visualizations were used to inquire into structural patterns (van Eck & Waltman, 2014). Network maps revealed relationships among high-frequency keywords and research clusters, while overlay maps highlighted temporal trends, enabling comparisons between early STEM-focused publications and recent studies integrating TVET competencies, employability skills, or Industry 4.0 technologies. Density maps aided the identification of thematic hotspots and underdeveloped areas, particularly those lacking strong connections to workforce readiness and vocational skills.

Analyses of themes and STEM-TVET integration
The clusters generated via VOSviewer were interpreted to identify dominant subfields, such as STEM pedagogy, teacher professional development, engineering design learning (EDL), technological literacy, and vocational skills alignment. Special attention was given to instances wherein STEM research was weakly linked to TVET curriculum modernization, industry collaboration, and competency frameworks, such as Industry 4.0 competencies. Therefore, this bibliometric layer provided a structural foundation for evaluating how STEM education research in Malaysia supports or diverges from the TVET strategies of the country.

RESULTS AND DISCUSSION

Sources and citations

Analyzing the number of publications in different years revealed the trajectory of research development in the field of STEM education in Malaysia. Such data were illustrated using a bar chart, from which we could visualize research activities and their changing trends. These activities have grown significantly over the past 15 years (Figure 2), reflecting the mounting importance of STEM education in Malaysia's education system. Especially in recent years, the number of published research has increased considerably given the weight that the government and educational institutions have attached to STEM education. These findings demonstrate not only the academic community's focus on STEM education but also the advancement of educational policy and practice in the context of interest.

With regard to core journals and topical issues, the *International Journal of Learning, Teaching and Educational Research* and the *Journal of Engineering Science and Technology* were the periodicals with the highest number of published articles during the time frame studied (Figure 3). These journals cover a wide range of STEM education research topics, including educational technology applications, teacher training, and the assessment of learning outcomes. In having their work published in these primary journals, researchers advanced scholarship on STEM education and provided important references for subsequent explorations. Notably, journals focusing on engineering and technology (*e.g.*, the *Journal of Engineering Science and Technology*) also served TVET-related domains, suggesting that STEM studies increasingly intersect with the discipline of vocational and technical education.

Popular terms and co-occurring keywords

The VOSviewer analysis of keywords in the 116 articles uncovered that the researchers used 391 keywords, of which 54 were mentioned more than twice. Table 1 shows the 10 most frequently adopted keywords and the cluster graph of principal terms that appeared more than two times in the articles. The term referred to most often was STEM (22), followed by STEM education (17), science education (12), and engineering education (9); project-based learning (PBL; 6) and education (6); and problem-based learning, e-learning, secondary school, and gender (4 times each). The keywords were divided into eight clusters, including STEM-related items, which were associated primarily with STEM disciplines and implementation levels; learning theory and learning technology; student development levels and learning effects; and teacher training (Figure 4).

Table 1: Top 10 popular keywords

No.	Keyword	Occurrence
1	STEM	22
2	STEM education	17
3	Science education	12
4	Engineering education	9
5	Project-based learning	6
6	Education	6
7	Problem-based learning	4
8	E-learning	4
9	Secondary school	4
10	Gender	4

STEM, science, technology, engineering, and mathematics.

The items discussed above are the areas to which STEM

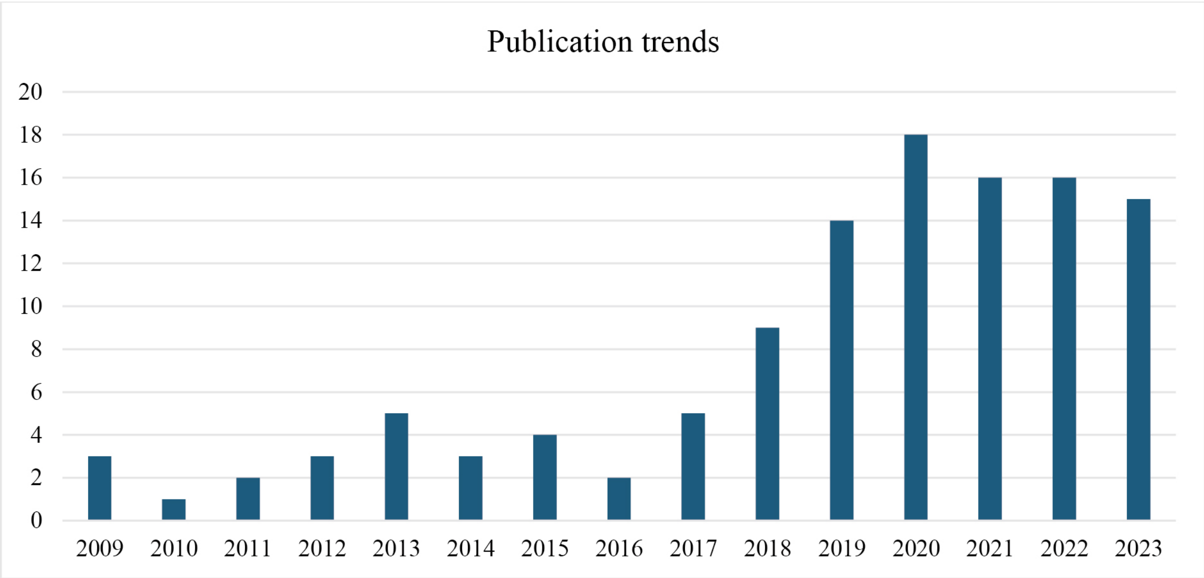

Figure 2. Publication trends for STEM education in Malaysia. STEM, science, technology, engineering, and mathematics.

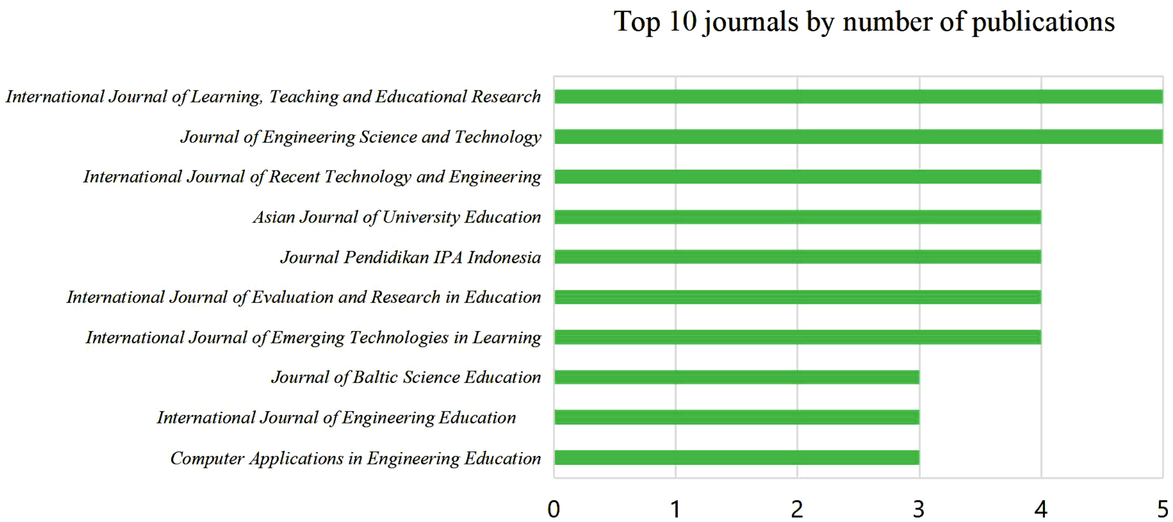

Figure 3. Top 10 journals by number of publications.

research was directed in Malaysia. VOSviewer was used to generate keyword frequency and co-occurrence networks to identify major research topics and their interrelationships. The keyword association analysis pinpointed several notable themes of STEM education research. High-frequency keywords such as STEM education, educational technology, teacher training, student attitude, and learning outcomes reflect the extensive exploration of how to enhance teacher training results, improve student attitudes, and enhance learning outcomes through educational technology. The keyword co-occurrence network also demonstrated the close connection between these topics, indicating that research on these issues is typified by strong relevance and intersectionality. For example, the considerable co-occurrence between STEM education and educational technology implies that researchers investigate approaches to the use of technology as a means by which to elevate the quality of STEM education. Interestingly, none of the frequently occurring keywords related directly to TVET, skills training, workforce readiness, or vocational pathways. This absence suggests a disconnect between Malaysia's national emphasis on TVET policy and the focus of STEM research.

Thematic analysis

Through literature analysis and VOSviewer visualization,

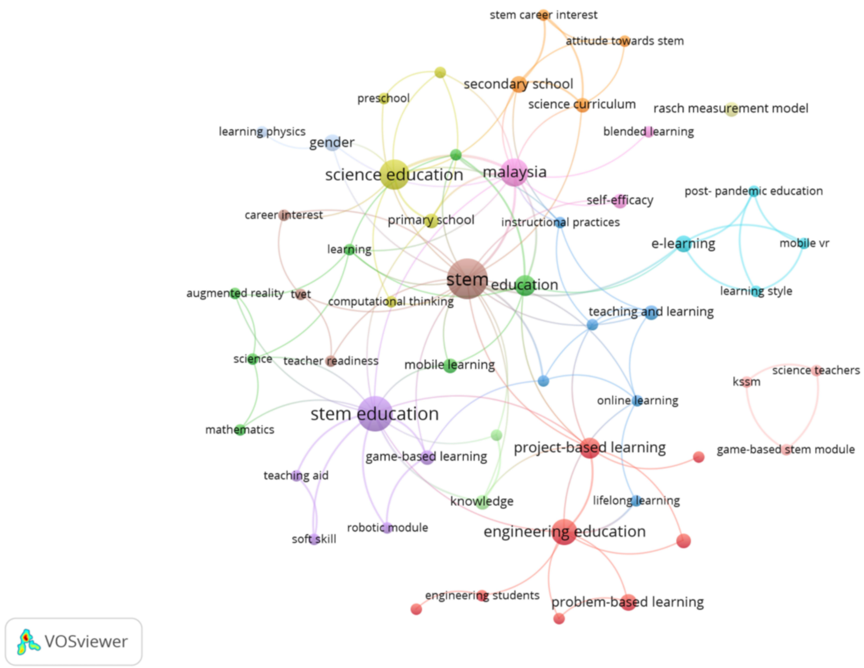

Figure 4. Network of STEM education in Malaysia. STEM, science, technology, engineering, and mathematics.

we organized eight principal themes of concern in the field of STEM education in Malaysia (Table 2).

STEM curricula

In the reviewed studies, discussions of STEM curricula centered on curriculum design and curriculum models. A case in point is Razali (2021), who designed a curriculum model for measuring interest in STEM careers. They verified the relationship between such interest and STEM, 21st century skills, scientific motivation, and family influence using S-STEM and an instrument designed to determine interest in STEM careers, the Science Motivation Questionnaire II, and the Parental Authority Questionnaire. Finally, the authors validated the effectiveness of the model of STEM career interest in motivating STEM learning. Endot and Jamaluddin (2023) investigated the student factors affecting the STEM curriculum systems in primary schools, while Karpudewan *et al.* (2023) discussed the influence of knowledge regarding different disciplines on teaching strategies, perceived difficulties, and self-efficacy in STEM curriculum integration. The latter put forward guidance on subject integration. Nasri *et al.*'s (2023) work revolved around the value-related issues involved in STEM curriculum communication and proposed strategies for addressing gender bias in STEM curricula. These studies discussed the design process as well as the development and effectiveness of STEM frameworks as reference for implementing STEM curricula from different perspectives.

Figure 5 presents the core content of STEM curricula in Malaysia, which encompasses STEM curriculum design, STEM integration, teaching strategies, social values, and equity in STEM curricula. The STEM curriculum models reviewed underscore 21st-century skills and engineering design thinking, which are directly relevant to frameworks concentrating on TVET skills. However, most of the studies did not explicitly connect STEM curriculum design to TVET competency frameworks, such as those centering on engineering technology skills, digital manufacturing, or applied technical problem-solving, which are required by Malaysian polytechnic universities and community colleges.

STEM fields

Of the studies reviewed, 63 and 53 discussed STEM in K-12 basic education and STEM at the university level, respectively, but slightly more discussions were devoted to the former. Nevertheless, the overall publication trend involving these domains was the same (Figure 6), indicating that Malaysian regions have no clear differentiation in terms of policy. The stronger popularity of K-12 education with researchers may reflect the concern of policymakers and scholars over the importance and impact of early education. The time trends showed that the number of studies increased significantly over the period 2009 to 2024, which is possibly linked to the series of education reforms and STEM promotion initiatives implemented by Malaysian authorities in recent years. In addition, STEM in basic

Table 2: Main topics of STEM education in Malaysia

No.	Main theme	Subtheme	Description
1	STEM curriculum	1. Curriculum design 2. STEM framework	1. Discussion of methods for designing suitable courses 2. Construction of STEM curriculum frameworks
2	STEM fields	1. Preschool 2. Primary school 3. Secondary school 4. University	Discussion of different situations in various fields
3	STEM learning theory	Theoretical basis	Discussion of theories on STEM
4	Technology in STEM	1. Application of learning method 2. Software in learning	1. Discussion of impacts of technologies on STEM 2. Discussion of the application of new technologies in STEM learning
5	STEM outcomes	1. Academic performance 2. Stem literacy 3. Stem identity	Discussion of 21st century skills and career competencies
6	STEM development level	Student performance level	Measurement of performance based on students' grades
7	Teacher training	Stem teacher training	Discussion of situations of STEM teachers and methods of instruction
8	Assessment	Evaluation of STEM results	Discussion of STEM curriculum evaluation and learning tools

STEM, science, technology, engineering, and mathematics.

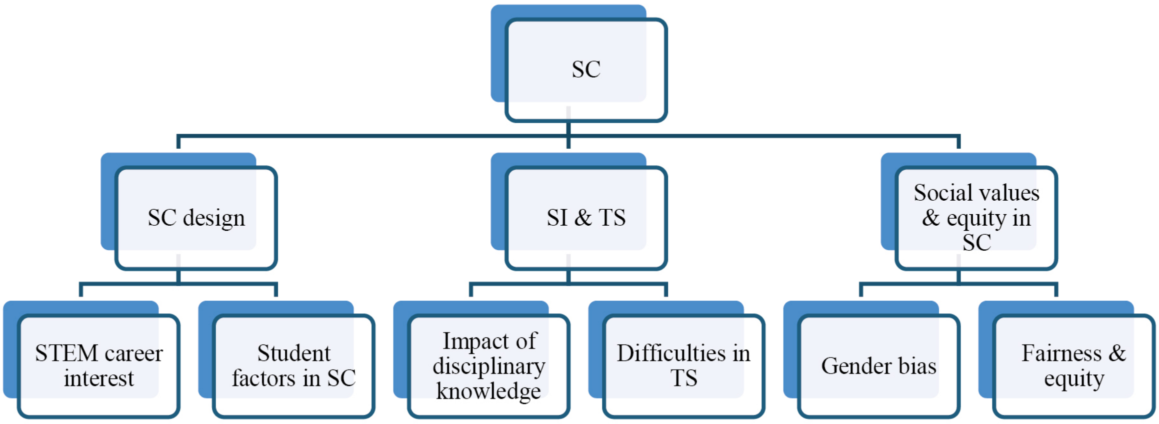

Figure 5. Focus of STEM curriculum research in Malaysia. STEM, science, technology, engineering, and mathematics; SC, STEM curriculum; SI, STEM integration; TS, teaching strategies.

education tended to be the focal issue in quantitative experi mental research. Among the 63 studies concentrating on K-12 education, 41 used quantitative methods, 12 employed qualitative approaches, and 10 were of mixed-method designs. Among the 53 explorations dedicated to the higher education context, 29 adopted quantitative approaches, 18 used qualitative methods, and 6 employed mixed-methods strategies. The overall development trend was basically identical, but qualitative scholarship on K-12 education was limited and focused mainly on STEM teaching methods, the cultivation of student initiative, and teacher training. Studies on higher education paid more attention to curriculum design, students' choice of majors, learning backgrounds, and the improvement of professional abilities. For example, several basic education studies prioritized the reasons for low STEM interest among middle school students. At the same time, we found that few studies were conducted on rural areas in Malaysia and obvious urban-rural research disparities exist. On the one hand, most existing research samples are mainly concentrated in urban educational institutions, resulting in insufficient sample coverage in remote and rural regions, which makes it difficult to obtain effective field research data. On the other hand, unbalanced regional STEM educational development across Malaysia leads to huge gaps in teaching resources, faculty strength, educational infrastructure and student learning conditions between urban and rural areas. Such distinct regional differences increase the difficulty of unified research design and empirical investigation, further restricting the progress of relevant rural-oriented research. While studies on K-12 dominated in terms of publication volume, minimal research explored how secondary STEM education prepares students for vocational colleges, polytechnic universities, or TVET career pathways—a notable shortcoming given national

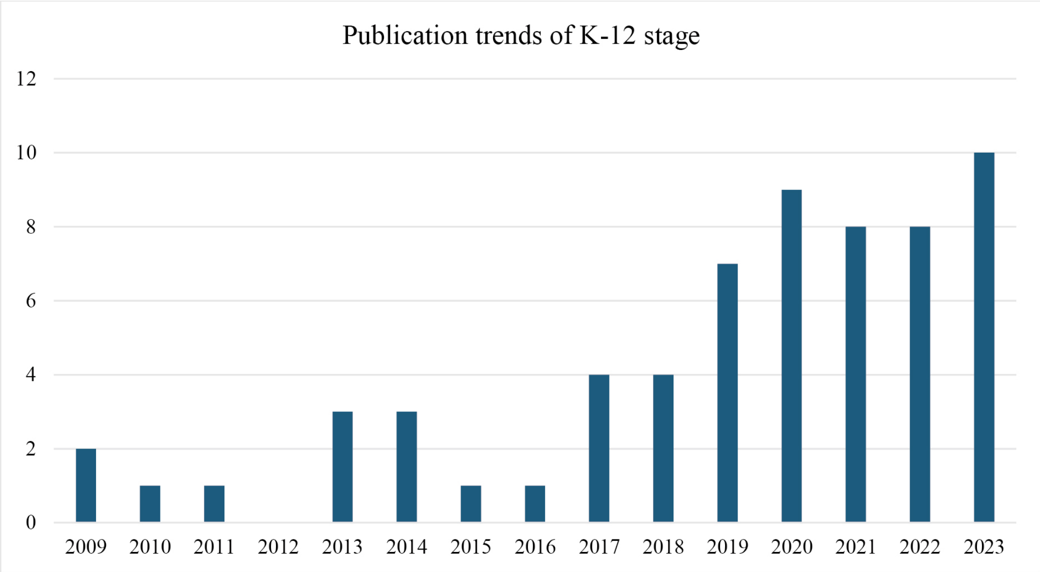

Figure 6. Publication trends for K-12 in Malaysia.

aspirations to increase TVET enrollment in Malaysia.

STEM learning theory

In STEM education research in Malaysia, different learning theories provide a rich conceptual basis for educational practice. The most common in this discipline are constructivism, behaviorism, cognitivism, socialized learning theory, and situated learning theory. These lenses provide a wealth of insights that inform teaching strategies, from strengthening basic skills to cultivating higher-order thinking and problem-solving abilities. For example, constructivism and problem- or PBL are used in many lessons, with emphasis placed on solving real-world issues through hands-on practice and cooperative learning in scientific experiments, engineering design projects, and so on (Navy & Kaya, 2020). Theoretical perspectives underscore various learning mechanisms and teaching methods, which promote students' comprehensive understanding and application of STEM knowledge. Researchers should focus on exploring how to effectively apply these learning theories in localized teaching practices. For example, PBL, EDL, and inquiry-based learning (IBL) strongly mirror the pedagogical approaches used in TVET institutions (authentic, competence-based tasks and experiential projects), yet the literature seldom links the two domains.

Technology in STEM

In STEM education research in Malaysia during the study period, various technological approaches were extensively used to enhance students' learning experiences and outcomes. Our analysis indicated that augmented reality (AR), smartphone applications, and online learning platforms were frequently adopted technical tools. For example, Ng *et al.* (2023) enhanced storytelling through the combination of virtual and AR to increase student interest and engagement in STEM, while Chu *et al.* (2023) asserted that sound experiments improve flexibility and interactivity in STEM learning. Online learning platforms likewise gained widespread popularity in recent years, particularly after the COVID-19 pandemic, amid the rapid development of basic education and higher education in Malaysia. As pointed out by Balakrishnan *et al.* (2019), online platforms for STEM learning not only promote collaboration and communication among students but also provide teachers with myriad instructional resources and assessment tools. The integration of technology into STEM education has therefore favorably affected STEM education in Malaysia, advancing the innovation of teaching methods and the optimization of instructional resources. Technologies such as AR, simulation applications, smartphone sensors, and virtual laboratories were also core tools in TVET environments aligned with Industry 4.0. Their shared pedagogical value suggests strong potential for STEM-TVET curriculum alignment. Figure 7 helps shed light on how technologies are integrated into STEM learning.

STEM outcomes

STEM outcomes were analyzed primarily from the perspectives of academic performance, skill development, career readiness, and long-term impact. Figure 8 illustrates the focal fields and perspectives explored in Malaysia during the period of interest. Some of the studies documented STEM subject achievement and the performance of STEM and non-STEM students in stan-

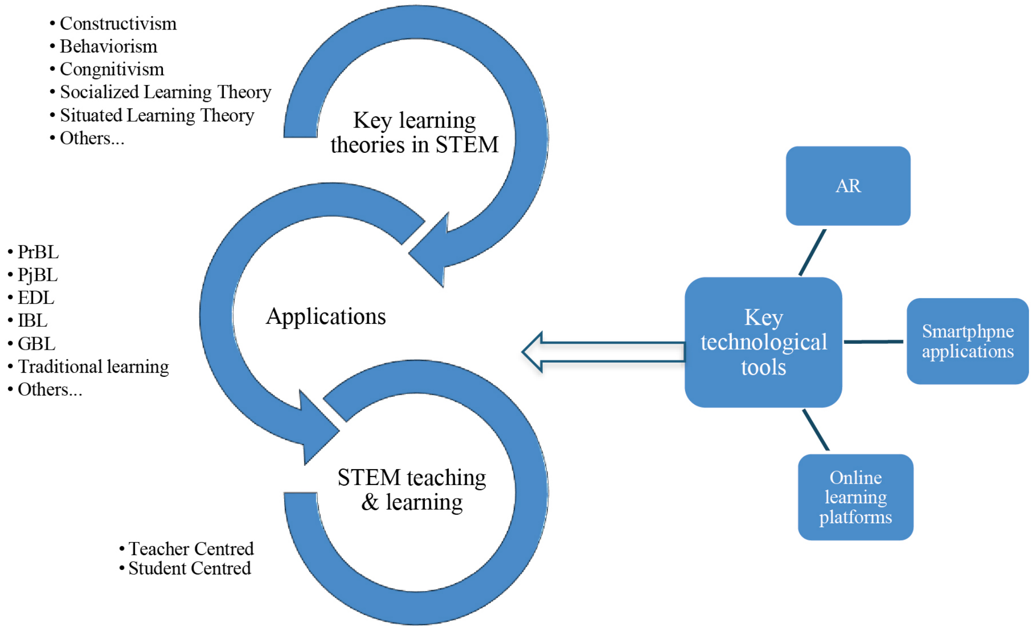

Figure 7. STEM learning theories and technology frameworks for STEM in Malaysia. STEM, science, technology, engineering, and mathematics; PrBL, problem-based learning; PjBL, project-based learning; EDL, engineering design learning; IBL, inquiry-based learning; GBL, game-based learning; AR, augmented reality.

dardized tests. Research on skills development concentrated mainly on the formation and development of competencies in the 21st century, the evaluation of students with respect to the 4Cs (communication, critical thinking, cooperation, creativity), problem-solving and digital competence, how STEM affects these abilities, and the changes occurring before and after the implementation of STEM education (Batiha *et al*., 2022; Daud *et al*., 2019; Dewi *et al*., 2023; Nasir *et al*., 2023).

Studies on career preparation dealt principally with interest in STEM careers, analyzed the impact of STEM on career interest, revealed changes in STEM career attitudes and interests, and evaluated the extent to which students cultivate the skills required for them to secure scientific, technological, engineering, and mathematical careers in the future (Alam *et al*., 2021; M. H. Ismail, 2022). Other explorations revolved around the preferences that high school and college students identify with respect to STEM-related majors and careers. Malaysia is also concerned about the long-term impact of STEM education, with research showing that such education has had a positive impact on students' participation in higher education and career development. Students receiving STEM education are more likely to enroll as STEM majors in universities and achieve career success in related fields. These students likewise offer more prominent contributions to social and economic progress. Many outcome variables—STEM literacy, digital skills, problem-solving, design thinking—are key employability competencies in the Malaysian qualifications framework, yet few studies have explicitly assessed how STEM outcomes support TVET readiness.

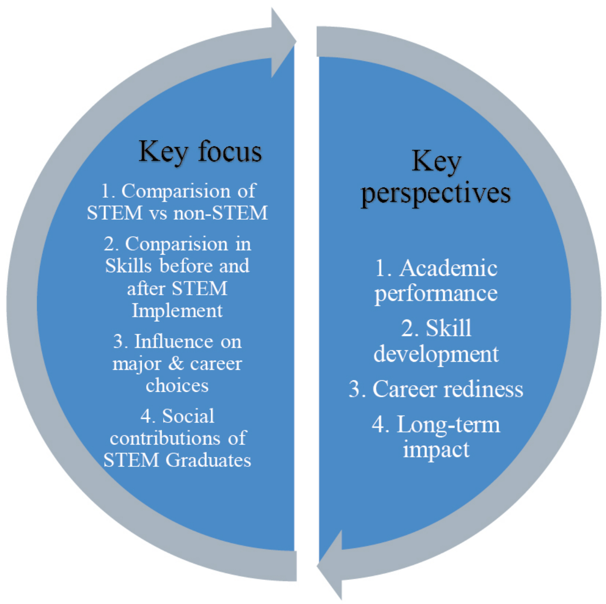

Figure 8. Research hotspots for STEM outcomes in Malaysia. STEM, science, technology, engineering, and mathematics.

STEM development levels

The analysis of STEM development levels among students in different grades comprehensively clarified the performance and advancement of STEM education in each stage of schooling. The research showed that the STEM development levels and foci in each stage differed across the period studied, serving as an important reference for optimizing the STEM education strategy implemented in each phase of education. For example, primary school centered on stimulating interest and cultivating basic knowledge in STEM through simple experiments and scientific and technological activities. Student interest in STEM fields was initially stimulated, after which STEM was integrated into math and science courses (Abdullah *et al*., 2021). In junior high school, focus was directed toward fostering primary programming skills and the ability to solve complex problems (Magaji, 2021; Shahali *et al*., 2017). STEM projects and competitions also gradually increased in prominence as avenues for learning, further promoting students' adeptness at cooperation, communication, and teamwork (Daud *et al*., 2019). This stage is similar to student-centered learning, as represented by PBL and EDL, in which students' practical competencies and STEM literacy are improved. In high school, students pursued more rigorous learning, covering advanced mathematics, physics, and technology courses. The data showed that students' interest in STEM careers increased significantly and that their levels of learning substantially improved given their participation in scientific research projects and experimental activities. University education was more inclined toward cultivating knowledge and competence in fields related to career development as well as training students in research and practice in professional domains such as innovation and project management. Although engagement with STEM during senior high school is a critical means of preparation for entry into TVET institutions, the review found limited research on how STEM learning influences students' selection of vocational or technical career pathways.

Teacher training

From 2009 to 2024, STEM teachers generally received systematic training in pedagogy and STEM expertise before joining the workforce, and they continued to attend various professional development training programs after employment; examples include continuing professional development (CPD) courses, workshops, and seminars (Hoon *et al*., 2022). These training programs cover the latest STEM instruction methods, technical tools, and curriculum design, thereby helping STEM educators improve their teaching abilities (Woo & Ashari, 2019). STEM teachers also adopted IBL, PBL, and other such approaches to elevate the quality of students' learning experiences, and they used technological tools such as multimedia and online learning platforms to increase the interactive atmosphere in the classroom and enhance the effects of teaching.

STEM teachers were equally instrumental in student assessment and feedback, with these professionals adopting diversified evaluation methods to help students better grasp concepts and insights. Figure 9 illustrates the five dimensions that constitute the closed loop of STEM teacher training: Pre-service training, in-service professional development, technology integration into instruction, teaching methods, and feedback and improvement. The results indicate that the status of STEM teacher training in Malaysia, including CPD and workshops, is consistent with the upskilling requirements of TVET instructors. Collaboration between STEM teachers and TVET lecturers can reduce the fragmentation between general and vocational education.

Assessment

The evaluation of STEM education in Malaysia during the period studied proceeded primarily through assessment standards, evaluation methods and tools, and feedback (Figure 10). Formative assessment was carried out through classroom tests, project reports, and other forms by which educators could understand learning progress and effects in a timely manner (Tak *et al*., 2023). Summative assessment was conducted at the end of a semester or the end of a long exam, after which a final study report is written to comprehensively summarize the performance of students across the entire STEM cycle (Tak *et al*., 2023). The assessment tools used included standardized tests, such as the PISA and the Trends in International Mathematics and Science Study (TIMSS), which were intended to evaluate math and science literacy, and program assessments of performance over the course of a program, covering program design, implementation, and outcome analysis (M. Z. Ismail *et al*., 2019). Technology-assisted assessment involved the use of online test platforms and educational software to increase the feasibility and interactivity of evaluations. Feedback was provided through written comments, oral feedback, and grading, which were meant to help students address their shortcomings as well as encourage them to reflect on and improve their learning initiative. The assessment tools used in STEM, such as project portfolios, performance tasks, and formative feedback closely aligned with the competence-based assessment frameworks employed in TVET. This alignment suggests strong potential for innovation in cross-sector assessment.

Realities of stem education: Alignments and differences with global standards

STEM education in Malaysia has been shaped by both global influences and local factors. Although the government has made significant strides and has kept pace

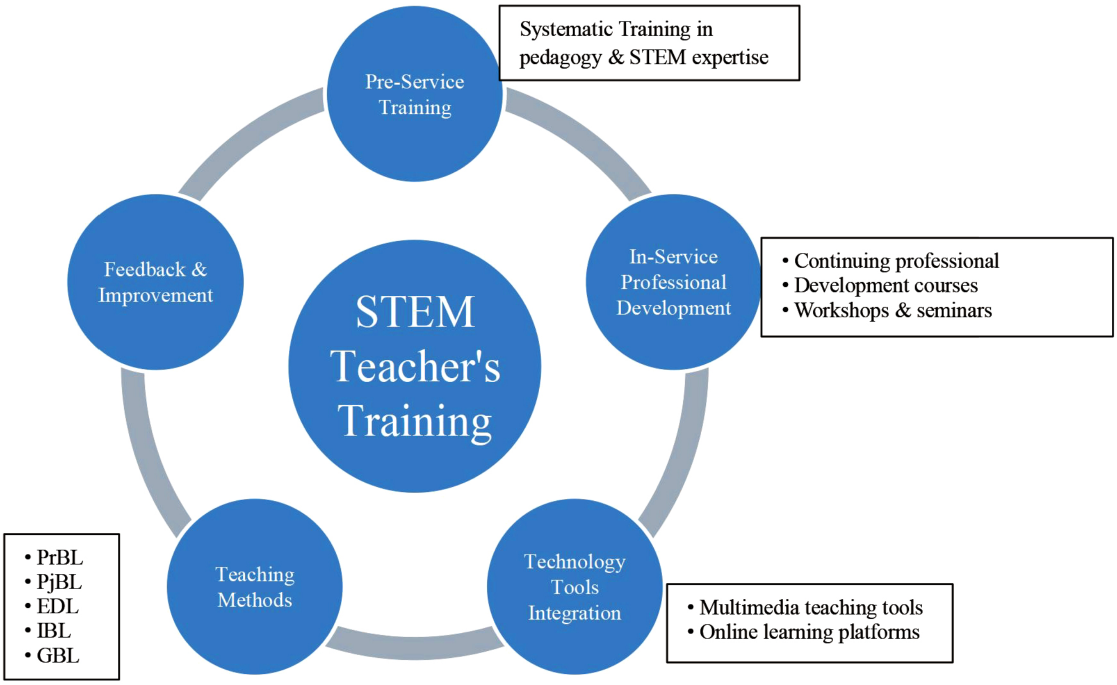

Figure 9. Conceptual framework for STEM teacher training in Malaysia. STEM, science, technology, engineering, and mathematics; PrBL, problem-based learning; PjBL, project-based learning; EDL, engineering design learning; IBL, inquiry-based learning; GBL, game-based learning; AR, augmented reality.

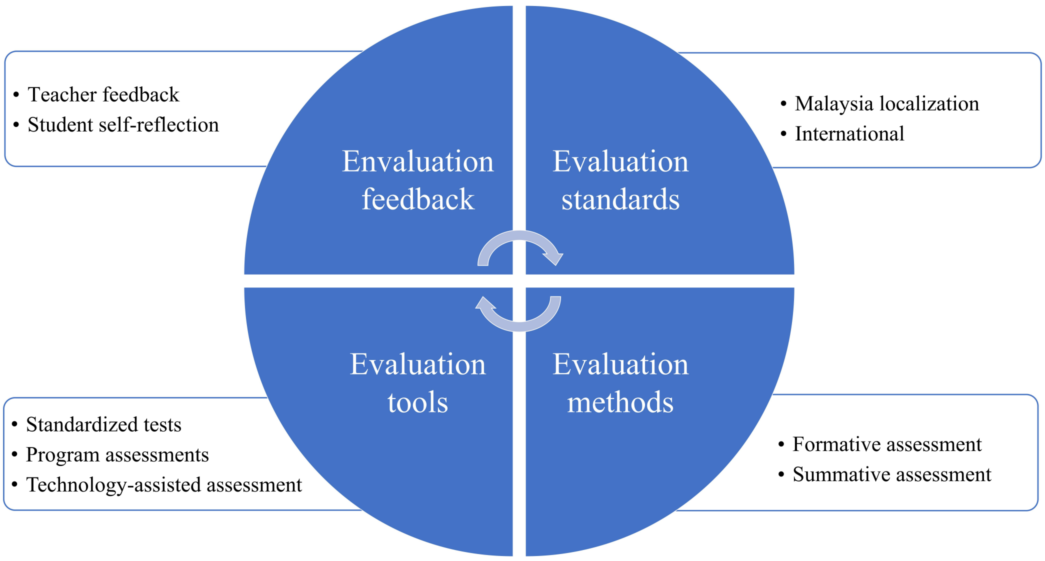

Figure 10. Four dimensions of STEM evaluation in Malaysia. STEM, science, technology, engineering, and mathematics.

with the core directions worldwide, conflicts continue to plague domestic endeavors. Malaysia has been working on STEM curriculum reform to achieve correspondence with the international emphasis on interdisciplinary learning (Leung, 2020), and its competence-based STEM reform parallels efforts exerted in the US, Europe, and East Asia (Freeman *et al*., 2019). The promotion of STEM literacy through the integration of computational thinking and problem-solving into various education sectors is also consistent with international goals. At the level of technology integration, Malaysia has adopted digital learning resources, such as online learning platforms, AR, and interactive tools, as was the case during the COVID-19 pandemic, pointing to alignment with the global trends of distance and digital learning (Miller *et al*., 2021). In addition, the country's foregrounding of 21st century skills, initiatives to address workforce needs in STEM sectors, and the exploration of student-centered teaching and learning for STEM also corresponds with international frameworks.

Despite these accomplishments, however, several aspects indicate divergence from global practices. Urban-rural disparities, for instance, burden Malaysia, with rural schools often lacking access to advanced STEM facilities and trained teachers. These problems, in turn, engender imbalances in learning outcomes and exacerbate the challenges confronting STEM-TVET integration (Abdullah *et al*., 2021; Ong *et al*., 2015). In contrast, countries with developed STEM systems, such as Germany and Finland, have implemented national policies to guarantee equitable STEM opportunities (Ishmuradova *et al*., 2023; Mäkelä *et al*., 2022). Malaysia likewise faces the problems of low interest in STEM careers and job market problems for STEM graduates, including minimal industry absorption, unlike the US and Germany, which has strong STEM employment ecosystems (Akcan *et al*., 2023; Kersanszki & Nadai, 2020; Reider *et al*., 2016). By addressing these differences and paying adequate attention to STEM, Malaysia can consolidate its position in STEM education and workforce development. Malaysia's STEM-TVET integration remains underdeveloped. For instance, countries such as Germany, Singapore, and South Korea have explicitly designed STEM pathways that feed directly into vocational high schools or technical institutes, whereas Malaysian STEM and TVET ecosystems operate separately under limited articulation mechanisms. Bridging this gap is essential for improving workforce readiness.

The reviewed studies reported shortages in qualified STEM teachers, minimal access to digital infrastructure, and inadequate laboratory and technical equipment in rural schools. These impede students' exposure to engineering-oriented, technology-intensive, and PBL experiences, thereby diminishing their readiness for advanced TVET pathways that attach considerable importance to technical competence and 21st century skills. As a result, rural students often face complex disadvantages not only in STEM participation but also in their transition to TVET, which exacerbate structural inequalities within the national talent development pipeline.

Barriers to STEM-TVET integration in Malaysia: A multidimensional perspective

Although Malaysia has introduced multiple national endeavors to advance both STEM education and TVET development, the literature indicated that effective integration between these domains remains constrained by several structural factors. From a policy perspective, the reviewed studies suggested limited coordination between general education reforms and vocational qualification frameworks. In particular, while the Malaysian Qualifications Agency (MQA) (Malaysian Qualifications Agency, 2024; Omar *et al*., 2019) has issued a formal structure for harmonizing learning outcomes across education levels, empirical research on how STEM curricula are mapped onto MQA competency levels or credit transfer mechanisms remains scarce, thus constraining the integration between secondary STEM pathways and TVET programs. From the standpoint of teacher capacity, the review uncovered a persistent skills and pedagogical gap. STEM teachers frequently lack exposure to industrial technologies and authentic Industry 4.0 applications, whereas TVET instructors often exhibit substandard pedagogical preparation for inquiry-based, interdisciplinary, and student-centered STEM approaches. This dual deficiency hinders the implementation of effective collaborative teaching practices and undermines the instructional foundation required for meaningful STEM-TVET integration. In addition, industry engagement continues to be an immature dimension in Malaysia's STEM education research. The bibliometric mapping showed that themes related to school-industry collaboration, workplace-based learning, and employer participation were treated as peripheral matters in the country's research landscape. The limited focus on industry-driven integration mechanisms further hampers alignment between STEM education outcomes and workforce demands.

CONCLUSION

This study demonstrated that Malaysia has achieved substantial progress in strengthening STEM education through strategic policy initiatives, curriculum reforms, teacher professional development, and investments in digital learning technologies. The increasing number of Scopus-indexed publications over the past 15 years covered in the review reflects growing national and academic commitment to advancing STEM learning. The thematic analysis highlighted major focal areas, including curriculum design and reform, the integration of STEM-related technologies into instruction, student learning outcomes, teacher competency development, and evolving assessment practices. Notwithstanding these encouraging accomplishments, a number of systemic challenges persist. The aforementioned significant urban-rural divide continues to obstruct equitable access to STEM resources, while disparities in teacher expertise and training quality constrain instructional effectiveness. Student interest and achievement in STEM remain subpar, particularly in secondary education. Furthermore, the insufficient alignment between STEM education and national labor market needs, especially within Malaysia's improving TVET ecosystem, reduces the overall impact of STEM measures on workforce readiness and economic transformation. Strengthening the connection between STEM learning outcomes and TVET competence requirements is therefore critical for ensuring that STEM reforms contribute meaningfully to Malaysia's Industry 4.0 blueprint.

Drawing on international STEM best practices, we propose several key directions for enhancing Malaysia's STEM ecosystem and regions facing similar issues regarding STEM-TVET integration. To enhance the effectiveness of such integration, a set of tiered and context-specific strategies consistent with the national education and skills development framework should be established. At the policy level, greater coherence is needed between STEM curriculum reform and MQA standards. Aligning STEM learning outcomes with TVET competence standards and strengthening credit transfer mechanisms would facilitate smoother transitions between general and vocational education pathways. At the institutional level, the expansion of the MQA can support collaboration between secondary schools, polytechnic universities, and TVET institutions. Joint curriculum design, shared facilities, and school-industry collaboration can help harmonize academic STEM learning with applied technical training. At the teacher level, targeted professional development program should promote cross-training between STEM educators and TVET instructors. Industry attachment schemes and collaborative teaching models, particularly in rural and under resourced areas, can increase instructional relevance and support the development of Industry 4.0-oriented competencies. Moreover, future research should incorporate additional databases and Malaysian local publications into analyses to derive exhaustive insights. Comparative studies across Association of Southeast Asian Nations (ASEAN) and other developing regions may further illuminate the contextual factors influencing STEM teaching and learning. Finally, more research is needed to examine the transition between STEM education and TVET pathways, including employability competencies, technical readiness, and partnerships between schools, industries, and vocational institutions.

By identifying the strengths and limitations of Malaysia's STEM ecosystem, this study offers evidence-based insights to policymakers, educators, and stakeholders. The findings not only inform national strategies for aligning STEM education with 21st-century demands but also serve as valuable reference points for other countries seeking to integrate STEM with evolving workforce and TVET priorities.

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Data availability statement

The data that support the findings are available from the authors upon reasonable request.

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