



# STEM Education in Malaysia: A Systematic Review of Learning Outcomes, Student Engagement, and Workforce Readiness in the Era of Industry 4.0

Omar Faruqi Marzuki<sup>1\*</sup>, Ellie Yi Lih Teo<sup>1</sup>, Wan Nor Zanariah Zainol @ Abdullah<sup>1,2</sup>, Nozieana Khairuddin<sup>1,2</sup>, Nor Hanifawati Inai<sup>1,2</sup>, Juniza Md Saad<sup>1</sup>, Mohd Hamim Abdul Aziz<sup>1</sup>, Nazrin Nurarief Mardi Asmawi<sup>1</sup>

<sup>1</sup>Department of Science and Technology, Faculty of Humanities, Management and Science, University of Putra Malaysia, Bintulu, Malaysia

<sup>2</sup>Institut EkoSains Borneo, University of Putra Malaysia, Bintulu, Malaysia

Email: \*omar\_faruqi@upm.edu.my

**How to cite this paper:** Marzuki, O.F., Teo, E.Y.L., Abdullah, W.N.Z.Z., Khairuddin, N., Inai, N.H., Saad, J.M., Aziz, M.H.A. and Asmawi, N.N.M. (2026) STEM Education in Malaysia: A Systematic Review of Learning Outcomes, Student Engagement, and Workforce Readiness in the Era of Industry 4.0. *Open Access Library Journal*, **13**: e15044. <https://doi.org/10.4236/oalib.1115044>

**Received:** February 19, 2026

**Accepted:** March 13, 2026

**Published:** March 16, 2026

Copyright © 2026 by author(s) and Open Access Library Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

STEM education is widely recognized as a driver of innovation and economic growth. In Malaysia, national initiatives such as the Malaysian Education Blueprint (2013-2025) and the National Policy on Science, Technology and Innovation (2021-2030) emphasize STEM as a pathway to workforce readiness. Despite these commitments, student enrollment in pure science streams remains low and learning outcomes are uneven, raising concerns about Malaysia's preparedness for a technology-driven future. This systematic review synthesizes recent empirical studies and meta-analyses to evaluate the impact of STEM education on higher-order thinking skills, academic performance, student motivation, and workforce readiness, with particular attention to the Malaysian context. Findings indicate moderate positive effects on cognitive and academic outcomes ( $d \approx 0.42 - 0.59$ ) and increased interest in STEM careers ( $\approx 78\%$  following program participation). However, this interest does not translate into sustained participation, with only 15.2% of students enrolled in pure science streams compared to the national target of 60%. The review suggests that this participation gap reflects systemic challenges, including exam-oriented pedagogy, uneven resource distribution, limited teacher preparedness, and socio-cultural influences. A contextualized STEM ecosystem framework is proposed to align policy, pedagogy, and industry collaboration to strengthen Malaysia's readiness for Industry 4.0.

## Subject Areas

Curriculum Development, Educational Reform

## Keywords

STEM Education, Malaysia, Higher-Order Thinking Skills, Workforce Readiness

---

## 1. Introduction

STEM (Science, Technology, Engineering, and Mathematics) education has become a strategic priority for nations seeking to strengthen innovation capacity and transition toward knowledge-based economies. Governments increasingly view STEM competencies as essential for technological advancement and workforce development in the Fourth Industrial Revolution. Malaysia has embraced this global shift through initiatives such as the Malaysian Education Blueprint (PPPM) 2013-2025 and the National Policy on Science, Technology and Innovation 2021-2030 [1].

STEM education is associated with the development of critical thinking, creativity, problem-solving, and analytical reasoning, competencies essential for navigating complex technological environments. Interdisciplinary approaches encourage students to apply knowledge across domains, making learning more relevant to real-world challenges [2]. In this review, a STEM program refers to structured educational initiatives integrating science, technology, engineering, and mathematics to promote interdisciplinary learning. Integrated STEM describes pedagogies that intentionally connect these disciplines through inquiry-based and project-based learning.

Despite policy support, Malaysia faces declining participation in STEM streams. Only 15.2% of secondary students enrol in pure science streams, compared to a national target of 60% [3]. This gap raises concerns about the country's ability to develop a sufficient STEM workforce. Contributing factors include exam-oriented teaching practices, limited career exposure, uneven resource distribution, and insufficient teacher preparedness [4].

In this review, higher-order thinking skills include critical thinking, creativity, problem-solving, and computational thinking. Workforce readiness refers to competencies such as digital literacy, collaboration, and adaptability required for modern labour markets.

Global meta-analyses report moderate improvements in learning outcomes from STEM interventions ( $d \approx 0.42 - 0.59$ ) [5], with stronger effects at the secondary level [6]. Malaysian studies further indicate increased interest in STEM careers following program participation, suggesting that targeted interventions can positively influence aspirations.

This paper contends that strengthening Malaysia's STEM ecosystem requires a

systemic approach that aligns policy aspirations with classroom practice, teacher capacity, and socio-cultural support.

## **Review Scope and Research Questions**

This review adopts an umbrella review approach combined with a Malaysia-focused narrative synthesis to examine the effectiveness of STEM education. The review addresses the following research questions:

- 1) What is the overall effectiveness of STEM education interventions in improving higher-order thinking skills and academic outcomes?
- 2) How do STEM programs influence student motivation, attitudes, and career aspirations in the Malaysian context?
- 3) What systemic factors explain the disparity between increased STEM interest and declining enrolment in Malaysia?
- 4) How can Malaysia strengthen its STEM ecosystem to support workforce readiness for Industry 4.0?

In this review, primary outcomes include higher-order thinking skills and academic performance, while secondary outcomes include student attitudes, motivation, creativity, and workforce readiness.

## **2. Literature Review**

### **2.1. Global Perspectives on STEM Education Effectiveness**

Over the past two decades, STEM education has evolved from discipline-specific instruction into an interdisciplinary framework aimed at fostering innovation, problem-solving, and workforce readiness. Contemporary approaches integrate cognitive, affective, and practical learning domains, reflecting constructivist and social cognitive theories that emphasize active learning and self-efficacy [6].

Meta-analytic evidence indicates that STEM education produces moderate improvements in learning outcomes. An umbrella review synthesizing over 1200 meta-analyses reported effect sizes of approximately 0.42 for academic achievement, 0.57 for higher-order thinking skills, and 0.59 for cognitive outcomes [5]. These findings suggest that STEM interventions are particularly effective in strengthening analytical reasoning and problem-solving rather than rote knowledge acquisition.

Evidence also suggests that STEM interventions may be especially impactful at the secondary level, where students begin forming academic identities and career aspirations [6]. However, some scholars caution that early exposure remains equally important, particularly when developmentally appropriate pedagogies such as game-based and maker-centered learning are employed. This ongoing debate highlights the need for sustained STEM engagement across educational stages.

### **2.2. Cognitive Skills, Creativity, and Computational Thinking**

One of the most consistent findings across literature is the positive influence of

STEM education on higher-order cognitive skills. Students engaged in inquiry-based STEM programs demonstrate improved critical thinking, analytical reasoning, and problem-solving abilities [7]. Interdisciplinary learning enables students to connect concepts across subjects and apply knowledge to real-world challenges, fostering deeper understanding [2].

STEM activities that incorporate coding, robotics, and design challenges also support the development of computational thinking and creative problem-solving. These skills such as abstraction, decomposition, and algorithmic reasoning are increasingly recognized as essential for digital literacy and innovation [8].

However, improvements in creativity appear less consistent than gains in analytical skills. Meta-analytic findings suggest that creativity outcomes depend heavily on pedagogical design, with project-based and maker-centered approaches showing greater effectiveness than content-driven instruction [6]. This suggests that creativity is not an automatic outcome of STEM education but requires deliberate instructional strategies.

### **2.3. Student Motivation, Attitudes, and Career Aspirations**

Student attitudes toward STEM significantly influence learning outcomes and career decisions. While university students generally report positive attitudes, interest among secondary students is more variable and may decline during adolescence [9]. This decline is concerning because secondary education represents a critical stage for career decision-making.

Experiential STEM activities including robotics, augmented reality, and project-based learning have been shown to enhance motivation and engagement. For example, hands-on interventions resulted in 82% of students reporting improved learning experiences and 92% supporting the integration of augmented reality tools [4]. Such findings underscore the importance of interactive learning environments in sustaining interest.

Motivation is also shaped by socio-cultural factors. Family support, access to role models, and perceptions of STEM careers influence students' willingness to pursue STEM pathways [3]. Students who lack confidence or exposure to STEM professionals are more likely to disengage, whereas those who perceive STEM careers as meaningful and attainable demonstrate greater persistence.

### **2.4. STEM Education and Academic Performance**

Research consistently indicates that STEM education can enhance academic performance, particularly in science and mathematics. STEM learning environments emphasize conceptual understanding and applied problem-solving, which contribute to deeper subject mastery [2]. Experimental studies demonstrate statistically significant improvements in post-test performance among students exposed to STEM-based instruction compared to traditional methods [10].

Nevertheless, improvements in academic performance are not uniformly distributed. STEM interventions tend to produce stronger gains in analytical do-

mains than in creativity-based measures [6]. This imbalance may reflect assessment systems that prioritize measurable cognitive outcomes over divergent thinking.

### **2.5. STEM Education in Malaysia: Trends and Challenges**

Malaysia has made significant policy commitments to STEM education, recognizing its importance for economic transformation and workforce development. National initiatives emphasize the need to produce a skilled workforce capable of supporting emerging industries such as artificial intelligence, cybersecurity, and data science [3].

Despite these efforts, participation in STEM streams continues to decline. Only 15.2% of secondary students enroll in pure science streams, far below the national target of 60%. This trend poses a significant challenge to Malaysia's technological competitiveness.

Malaysian studies provide evidence that STEM initiatives can enhance student interest. For instance, a program aligned with national education goals reported that 78% of participants expressed increased interest in STEM careers, particularly engineering [1]. However, this increased interest does not consistently translate into sustained enrollment.

Several barriers contribute to this disconnect. Exam-oriented teaching practices may limit inquiry-based learning and reduce student confidence. Unequal access to laboratories and digital tools restricts hands-on learning opportunities, particularly in rural schools. Additionally, limited exposure to STEM careers and role models weakens students' perceptions of STEM pathways as attainable [4].

### **2.6. Equity and Inclusivity in STEM Participation**

Equity issues in STEM education extend beyond gender to include geographic and socioeconomic disparities. While some studies report minimal gender differences in STEM attitudes, resource disparities between urban and rural schools remain a significant concern [3]. Schools with limited infrastructure face challenges in implementing advanced STEM tools, potentially widening the digital divide [4].

Ensuring equitable access to STEM resources is essential for inclusive education and national capacity building. Without targeted interventions, disparities in access may undermine efforts to expand STEM participation.

### **2.7. Synthesis and Research Gaps**

The literature indicates that STEM education has significant potential to enhance cognitive skills, academic performance, and workforce readiness. However, several gaps remain. First, effectiveness varies depending on pedagogy, teacher expertise, and resource availability, highlighting the need for context-sensitive implementation models. Second, declining student interest in Malaysia raises questions about the sustainability of STEM pipelines despite positive learning outcomes. Third, longitudinal studies tracking students into the workforce remain

limited. Finally, creativity outcomes are inconsistent, suggesting the need for pedagogies that explicitly foster innovation.

Taken together, the literature suggests that while STEM education is widely promoted as a driver of innovation, its effectiveness remains contingent upon contextual factors that are often overlooked in policy discourse.

### **3. Methodology of the Review and Conceptual Framework**

#### **3.1. Review Design and Approach**

This study employs a systematic narrative review combined with quantitative synthesis to examine the effectiveness of STEM education, with a focus on Malaysia. The review integrates empirical studies, quasi-experimental research, and global meta-analyses published between 2023 and 2025. This integrative approach enables triangulation across diverse research designs and provides both global benchmarks and context-specific insights.

An umbrella review approach was adopted to synthesize global meta-analyses alongside a Malaysia-focused narrative synthesis. Global evidence provides a benchmark for understanding overall STEM effectiveness, while Malaysian studies offer contextual insights into local implementation and participation trends [5]. These evidence streams were analyzed separately to avoid double counting and to ensure clarity in interpretation.

Primary outcomes examined include higher-order thinking skills and academic performance, while secondary outcomes include student attitudes, motivation, creativity, and workforce readiness.

#### **3.2. Search Strategy and Study Selection**

A systematic search was conducted through Scopus, Web of Science, ERIC, and Google Scholar to identify relevant studies published between January 2023 and March 2025. Search strings combined keywords such as “STEM education,” “integrated STEM,” “higher-order thinking,” “learning outcomes,” and “Malaysia,” using Boolean operators.

The search process followed a multi-stage screening procedure:

- 1) Title screening to remove clearly irrelevant studies
- 2) Abstract review to assess relevance to STEM outcomes
- 3) Full-text assessment to confirm eligibility

Studies were excluded if they lacked empirical evidence, did not report educational outcomes, were not peer-reviewed, or were unrelated to STEM education.

The study selection process followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and reproducibility. Records identified through database searches were screened through a multi-stage process involving title review, abstract assessment, and full-text evaluation based on predefined inclusion and exclusion criteria. Studies that did not meet the eligibility criteria were excluded at each stage, resulting in a final set of studies included in the synthesis.

### 3.3. Data Analysis and Synthesis

Findings were synthesized using thematic analysis supported by quantitative indicators. Outcomes were grouped into five categories: cognitive and academic outcomes; student attitudes and motivation; creativity and computational thinking; participation trends; and implementation barriers.

Because this review synthesizes findings from existing meta-analyses rather than conducting a new meta-analysis, effect sizes were extracted as reported in the original studies and were not recomputed or converted. Reported effect sizes were standardized mean differences (Cohen's *d*), interpreted using conventional benchmarks (small  $\approx 0.2$ , medium  $\approx 0.5$ , large  $\approx 0.8$ ). A random-effects perspective was adopted in interpreting results to account for variability across educational contexts and study designs. Heterogeneity reported in the original meta-analyses was considered qualitatively when evaluating consistency of findings. When multiple outcomes were reported within a single study, outcomes were categorized by domain (cognitive, affective, academic) to prevent double counting.

### 3.4. Quality Appraisal and Risk of Bias

The methodological quality of included empirical and quasi-experimental studies was appraised using criteria adapted from education research appraisal frameworks. The appraisal considered research design clarity, sample adequacy, validity of measurement instruments, transparency of analysis, and alignment between research questions and conclusions.

Studies demonstrating stronger methodological rigor were given greater interpretive weight, while findings from studies with potential limitations were interpreted cautiously. This approach ensured that conclusions reflected both the strengths and limitations of the available evidence.

### 3.5. Methodological Limitations

Variations in research design, measurement tools, and contextual factors limit direct comparability across studies. In addition, reliance on published literature may introduce publication bias. Despite these limitations, the combined use of thematic synthesis and quantitative indicators provides a balanced and transparent understanding of STEM education outcomes.

## 4. Conceptual Framework: Malaysia's STEM Education Ecosystem

### 4.1. Rationale for a Contextualized Framework

The literature examined in this article indicates that STEM education outcomes are determined by an intricate web of factors, including pedagogy, teacher capacity, resources available, socio-culturally-oriented factors, and policy support [6]. As such, a linear model of educational reform alone will not adequately reflect the dynamic interrelationships involved. To understand how these different components interact within Malaysia's educational context, we need to use a systems ap-

proach.

This is because Malaysia's STEM ecosystem is impacted not only by national policy, but also by institutional practice, community expectations, and economic priorities. Although the policy framework focuses on development and a workforce-ready generation, the decline in participation rates indicates a disconnect between policy goals and what happens in the classroom. This highlights the importance of an overarching framework for STEM education that represents the complex multi-dimensional relationship of STEM education.

## 4.2. Proposed STEM Ecosystem Framework for Malaysia

According to the proposed framework, STEM education is a multi-layered ecosystem represented as 5 interconnected domains. These domains do not operate independently of one another, but rather they dynamically interact with each other to affect student engagement, student learning outcomes, and student workforce readiness.

### 1) Policy and Governance Layer

National Policy on Science and Technology/Innovation and the PPPM (Malaysian Education Blueprint), set the direction for STEM education and provide the national level strategies for supporting the development and delivery of STEM education. They seek to produce a workforce skilled in STEM, which will contribute to the transformation of the economy [3]. Yet the targets outlined in both policies for the enrolment of students in STEM have not been reached (60% target), which means there are continuing gaps between policy and implementation.

### 2) Pedagogical and Curriculum Layer

Instructional methods, curricular integration and evaluation practices make up the encompassing layer. Significant evidence indicates that inquiry-based learning, project-based learning, and interdisciplinary approaches produce improved student learning outcomes [7]. However, in Malaysia, the existing culture of examination-oriented learning and inflexible curricular limits the implementation of inquiry-based, project-based, and multidisciplinary instruction [4]. The general absence of design thinking and creativity-focused instruction also limits opportunities to develop innovative competencies.

### 3) Teacher Capacity and Professional Development Layer

The degree of teachers' preparedness is one of the most important aspects influencing the effectiveness of STEM programs. Many teachers indicate they were inadequately prepared to teach through an interdisciplinary instructional approach and use of new technology, which also decreases their self-efficacy when delivering Integrated STEM content [4]. The difference between professional development opportunities for teachers in urban versus rural areas leads to inconsistencies in the level of instruction provided to students. To overcome these issues, continued investment should be made in providing quality training for teachers and supporting them with proper systems.

### 4) Student Engagement and Socio-Cultural Layer

Students' attitude, self-efficacy; family support; and career awareness are factors

shaping student's participation in STEM areas [3]. Students' interest may be reduced by lack of examples to follow in STEM related career pathways; but family or community encouragement will encourage students to become interested in STEM. Self-efficacy is a strong indicator of a student's ability to continue pursuing a STEM pathway.

#### **5) Infrastructure and Industry Collaboration Layer**

Numerous sources of research [4] support the assertion that high-quality access to laboratories, robotic kits, digital tools, etc. is a major factor affecting the implementation of STEM. The reduced opportunities of hands-on learning due to resource imbalances in schools creates disparities in how well students receive an equal education regardless of where they live; more restrictive collaboration between schools and businesses has created a less connected environment for students to see how they can apply STEM in their lives after graduation.

### **4.3. Interactions within the STEM Ecosystem**

This framework provides important insight that these layers interact and depend on each other. For example, if there is a reform to policies but no training for teachers, then the reforms may not have much impact. Conversely, if infrastructure improvements occur but no change in pedagogical practice occurs, then improvements in the results will be limited at best. Additionally, when socio-culture around students matches their career paths, student motivation will be more likely to increase.

A systems view can help to explain why Malaysia continues to have low levels of STEM participation despite strong policy commitment. For an effective reform process to occur, there needs to be a coordinated intervention across multiple layers, instead of independent or isolated interventions.

### **4.4. Implications of the Framework**

The proposed ecosystem framework offers a basis to align policy and classroom practice as well as create targeted interventions. It identifies the need to improve teacher training, address rural resource inequities, strengthen partnerships with industry, and increase student career awareness. By addressing these interrelated domains together, Malaysia can increase participation in STEM, strengthen student achievement, and support workforce readiness for Industry 4.0.

## **5. Results and Discussion**

### **5.1. Overall Effectiveness of STEM Education in Learning Outcomes**

The findings of both research studies and meta-analyses previously examined indicate a moderate impact on improving student learning because of STEM education [5]. The average effect size for academic and cognitive outcomes is 0.42 and 0.59 respectively, across multiple countries indicates that there was significant positive impact because of implementation of STEM programming [5]. The small

to moderate effect sizes by themselves would not indicate a “transformational change”; however, the accumulation of statistically significant effects observed, particularly when active inquiry methods are used for STEM delivery, demonstrate that the benefits of STEM are consistent across multiple studies.

In addition to that, evidence suggests that some of the strongest impacts of STEM education are found at the secondary level. Examining effect sizes from the subgroup analyses reveals that the average effect size for adolescents (15 - 19 years old) is approximately 0.58, indicating that this age group is of critical importance to engage and support with STEM [6]. Thus, although it may be premature to draw firm conclusions about the limited value of early interventions, this information strengthens the argument for continued and appropriate STEM exposure throughout all levels of education.

This is especially true in Malaysia; students are faced with the critical decision at secondary school to choose between the science stream and a non-science stream, an early decision that influences their future academic and career paths. Based on data available from the Ministry of Education [3], the participation rate for Malaysian secondary school students currently is 15.2% in the pure science stream, which is below the target of 60% [11]. It is possible that while participating in the science stream will improve student outcomes, the disparity in participation rates suggests a lack of sufficient other influences, such as systemic and socio-cultural factors, that will encourage students to commit to pursuing an education in the pure sciences.

## **5.2. Impact on Critical Thinking, Problem-Solving, and Cognitive Skills**

Research consistently highlights the substantial impact of STEM education on students' ability to think at higher order cognitive levels. Research has shown that students who participate in STEM-based programs often display higher levels of critical thinking skills compared to those who do not participate; inquiries, experimentation, and collaboration are integral to these programs [7]. Participation in these types of learning experiences promotes the student's ability to evaluate evidence, test their hypotheses, and revise their solutions in ways that can be utilized in other contexts outside of the classroom.

Furthermore, STEM education has been linked to increased analytical reasoning and systems thinking which are essential skills in technologically complex environments. Interdisciplinary learning (the integration of mathematics, science, and engineering) enables students to apply their theoretical understanding of course content to real-world applications, providing deeper conceptual associations [2].

In contrast, exam-oriented methods of teaching and assessment in Malaysia may limit the opportunity for students to engage in the inquiry-based method of learning [4]. Standardized testing can serve as a useful means of measuring student achievement, however, an over-reliance on memorization can inhibit stu-

dents from experimenting with the subject matter and limit their confidence in problem solving. Thus, there is a pressing need to create a balance between assessment criteria and teaching methods that promote exploration and critical inquiries.

### 5.3. Creativity and Computational Thinking Outcomes

STEM education has shown consistent improvement in cognitive skill enhancement. However, with creativity in the STEM education enhancements, there appears to be diverse results, with multiple studies showing large gains in creative thinking via the implementation of STEM educational interventions, especially if the intervention includes activities such as Coding, Robotics, and Design Challenges [8]. These experiences develop foundational computational thinking skills (such as Abstraction, Decomposition, and Algorithmic Reasoning), with these skills being recognized as essential for Digital Literacy.

Moreover, although creativity gains are substantial from STEM educational programs, meta-analytic studies have shown considerable variation [6]. As an example, STEM programs that are primarily focused on content-based delivery of knowledge have not produced increased innovative thinking but do produce more information. Alternatively, Project-Based Learning or Maker-Centered Learning approaches appear to be far better at promoting Innovation and experimentation.

Such differences are notably important in Malaysia. Despite strong national emphasis on Innovation, classroom practices are often still primarily focused on content delivery. STEM education's capacity to promote innovative thinking has great potential if educational institutions in Malaysia embrace pedagogical changes reflective of Design-Thinking and Open-Ended problem solving.

### 5.4. Student Motivation, Attitudes, and Career Aspirations

The impact of students' attitudes toward STEM is significant as they shape both the learning outcomes of their students as well as their students' perspectives and decisions related to future careers. In Malaysia, research shows participation in STEM programs drives interest in pursuing STEM careers; students reported increased interest in STEM careers post program participation (78% of participants; [1]). Based on this finding, there are indications that interventions designed to support student aspirations can be positively impacted by programs designed around the relevance of STEM to the real world.

However, the global perspective of STEM interest varies across levels of education. Students report a positive interest in STEM while they are engaged in university education; however, the secondary school students exhibit variable interest levels, with data suggesting a decrease during adolescence [9]. The decline in interest during adolescence is alarming because it is a critical point in the career decision making process for an individual.

Additionally, socio-cultural influences can have an impact on student motivation in pursuing a career within the STEM field. Factors such as familial support,

availability of role models, and perceptions of STEM careers shape students. Students who lack confidence in themselves and have limited exposure to STEM professionals will show a lower degree of engagement as time goes on. Conversely, when students perceive STEM careers as valuable to them as a means of achieving success in society, they continue to be engaged and enthusiastic about their pursuit of education in the STEM fields.

This research indicates that any efforts to improve participation among students in STEM via reforming education will not achieve optimal results without having an emphasis on career awareness programs; mentorship programs, and community outreach programs to sustain student interest in STEM.

### **5.5. Academic Performance and Knowledge Acquisition**

Research has consistently shown that STEM education improves academic performance, especially in Science and Mathematics. STEM learning environments usually focus on understanding concepts and applying problem-solving skills, both contributing to the acquisition of deeper content knowledge [2]. Experimental studies have found statistically significant differences between post-test performance from students who have had access to STEM instruction compared to those who received instruction through traditional methods [10].

In the Malaysian context, STEM mentoring programs have reported very high mean scores for both knowledge acquisition and project development skills, suggesting that through hands-on activities students not only learn concepts, but also develop practical skills [4]. However, there are many students still at a beginner level regarding solving problems; therefore, short-term interventions may not help to achieve mastery.

These results indicate the need for continuity in STEM education. Sustained experience with STEM education, as opposed to isolated STEM programs, will produce lasting improvements in both academic performance and workforce readiness.

### **5.6. Barriers to Effective STEM Implementation in Malaysia**

STEM education within Malaysia, despite its potential benefits, has several systemic challenges that hinder its success. One of the major problems is that the education system focusses on high-stakes testing limits inquiry-based learning as well as ability to create [4]. The substantial emphasis placed on standardized assessments has created an accountability mechanism that may discourage pedagogy innovation.

Another major issue is the preparedness of teachers to implement STEM education. Many teachers have reported feeling not well trained to provide interdisciplinary STEM instruction and are not confident in using current technologies to teach integrated content [4]. Disparities exist between the professional development resources of teachers working in urban areas compared with those in rural area solutions.

The unequal distribution of resources has created significant barriers in providing equitable access to hands-on learning opportunities. Schools that are in rural and/or underfunded areas rarely have laboratories, robotics kits or digital tools, leading to a very limited number of opportunities for hands-on experiential learning. By not being able to provide hands-on experiential learning opportunities, schools risk further widening the gap in education levels of children in these areas and reducing overall capacity of STEM within the country.

Finally, different socio-cultural factors influence motivation to pursue STEM career paths. Students who have low self-efficacy, limited support from family, and who do not know people working in STEM fields are less likely to consider pursuing STEM careers. The continued influence of these factors will remain in place unless there are purposeful efforts made to create experiences that will change this perspective.

### **5.7. Malaysia in the Context of Industry 4.0 Workforce Needs**

As the Industry 4.0 era begins, the workforce will require a higher level of education to meet the demands of the labor market. In particular, the demand for digital literacy, computational thinking, and interdisciplinary problem-solving skills is growing rapidly. STEM education is regarded by many stakeholders as playing an essential role in preparing the next generation of workers to enter the workforce in fast-growing sectors such as artificial intelligence (AI), cybersecurity, data science, renewable energy, and smart agriculture.

However, with only 15.2% of Malaysian students enrolled in pure science streams, the supply of graduates to support the country's innovation objectives may be inadequate [3]. In contrast, there is evidence that well-designed STEM programs have positively influenced career interest and workforce readiness [1]. Thus, scaling effective interventions will be one way to help mitigate this challenge.

### **5.8. Integrated Discussion: Explaining the Participation Paradox**

The current paradox of the Malaysian STEM environment shows positive learning outcomes contrasted by a decrease in school-aged participation. This study concludes that the problem is multifaceted and attributed to the dynamic interaction of systemic, pedagogical and socio-cultural factors.

Although there are aggressive policy initiatives creating goals for growth, there still exists a large consistency between exam-focused systems and these goals. There is also a disparity of investment in infrastructure that will promote STEM education development across geographic regions, despite improved outcomes of students participating in STEM programming. Limited exposure to potential career opportunities, as well as socio-cultural influences, continue to limit students' long-term participation within the STEM workforce.

To resolve the paradox of low participation rates while having positive learning outcomes for students, a comprehensive system-wide solutions approach is rec-

ommended. Stand-alone interventions will not be capable of producing sustainable changes without interventions within the pedagogy, professional development of teachers, distribution of resources, and career awareness. By developing a holistic strategy that aligns policy, practices, and city-wide commitment, the Malaysian STEM ecosystem will be further established and strengthened. Therefore, this study has proposed that the paradox that is shown within Malaysia's level of STEM participation cannot be resolved through stand-alone interventions but rather is a display of systemic misalignment that has created a need for coordinated reform throughout the various levels of the educational ecosystem.

National enrollment figures cited in this review are derived from Ministry of Education reporting summarized in [3], which indicate that only 15.2% of secondary students are enrolled in the pure science stream, compared to the national target of 60%. This persistent gap suggests that policy aspirations have not translated into sustained participation.

The Malaysian studies included in this review point to several plausible mechanisms explaining this disconnect. First, exam-oriented pedagogy may reduce students' confidence in applying STEM knowledge to real-world contexts, leading to disengagement despite adequate academic performance. Second, unequal access to laboratories, digital tools, and hands-on learning opportunities particularly in rural schools' limits students' exposure to authentic STEM experiences. Third, limited awareness of STEM career pathways and the absence of relatable role models may weaken students' perceptions of STEM as attainable or relevant.

Taken together, these mechanisms help explain why increased interest generated by STEM programs does not consistently translate into sustained enrollment. This review therefore suggests that addressing the participation paradox requires systemic reforms that extend beyond classroom interventions to include career exposure, resource equity, and pedagogical transformation.

## **6. Recommendations and Policy Implications**

As demonstrated through this analysis, no one solution will alleviate the myriads of challenges described above; however, implementing multiple types of strategies (e.g., teacher training) will yield significantly better outcomes compared to trying to address the same issues independently of each other.

### **6.1. Aligning Policy Ambitions with Classroom Realities**

Malaysia's government has set out clear plans to develop STEM education through national education programs such as the PPPM (2013-2025) and the National Policy on Science, Technology and Innovation (2021-2030). Both documents represent an ambitious vision to develop a workforce skilled in STEM to help develop the country's economy. However, despite these documents' ambitious goals, only 15.2% of students enrolled in STEM-related subjects at the various levels of Malaysian public schools [3].

While low enrollment does not necessarily mean that Malaysian policymakers'

goals are unattainable, it does indicate how complicated educational improvement is, with many variables impacting outcomes such as school policies, the availability of resources and cultural differences among students. Moving forward, aligning policies with their implementation may require better mechanisms for monitoring and evaluation, clearer student outcome measures, additional resources for school reform and other types of support for schools implementing change. Additionally, instead of just focusing on the high school graduation rate and number of students enrolled in a STEM class, Malaysian policymakers should also consider other ways to measure STEM involvement, including participation in STEM initiatives that take place outside of regular school hours (e.g., STEM-related projects, competitions and community initiatives).

### **6.2. Reconsidering Pedagogical Priorities**

There is a consensus in the literature [7] that STEM outcomes are improved through inquiry-based, project based, and interdisciplinary methodologies; nevertheless, the current prevalence of exam focused pedagogy in Malaysia, restricts the implementation of these methodologies [4]. This tension is symptomatic of a wider problem facing educational systems globally which is to balance the need for accountability with the need to develop creativity and critical thinking skills.

A gradual transformation in assessment methodologies may be required to facilitate innovations in pedagogy. By including project-based assessment, design challenges, and collaborative problem-solving tasks within the overall assessment process, schools may more accurately assess the extent to which their students are learning and provide opportunities for exploration and creativity. Changes in assessment methodologies need not completely replace standardized assessments; instead, they could augment the existing system enabling schools to develop both conceptual understanding and innovative thinking in their students.

### **6.3. Strengthening Teacher Capacity as a Cornerstone of Reform**

Perceived teacher readiness is one of the primary components that are related to effective STEM education. Most teachers who have a high level of subject matter knowledge related to STEM also reported low levels of preparedness to implement interdisciplinary STEM education and emerging technologies within their classrooms [4]. To address this skill gap, there needs to be more than just short-term workshops; rather, there needs to be a sustained effort toward providing professional development opportunities to allow teachers to continuously learn.

Some possible professional development opportunities may include building collaborative practice communities, developing mentor relationships, and working with industry partners to provide teachers with opportunities to see how STEM is being implemented within the workforce. Such experiences can assist teachers in developing ways to connect theory to practice and help them find ways to make their instruction more meaningful and engaging for their students. In addition, providing equitable access to professional development should also be a

priority for teachers who work in rural areas.

#### **6.4. Addressing Socio-Cultural Influences on Student Participation**

The influence of student motivation and college aspirations are multi-fold and multi-faceted, with research suggesting that self-efficacy, encouragement from family's network of support, and access to role model's leads to greater success in pursuing STEM pathway's [3]; therefore, without addressing the above-mentioned issues, any improvements in curriculum/pedagogy will likely have only limited impact on long-term self-efficacy.

Providing students with greater awareness of career pathways to STEM professions, including school-industry mentoring, outreach by STEM professionals and opportunities to engage with the community through STEM-related programs may allow students to see various career options, thereby removing the mystery surrounding those professions and providing further affirmation that STEM professions are viable career choices that offer social value.

#### **6.5. Reducing Urban-Rural Disparities in STEM Access**

There is an ongoing issue of unequal access to resources and facilities in Malaysian schools, particularly between rural and urban regions, which represents a large barrier to the implementation of experiential learning in the STEM areas with schools lacking facilities such as labs, digital resources or sustainable internet connectivity being unable to conduct hands-on STEM-based activities [4]. As these resources are not equally distributed between the urban and rural regions, this will create and further marginalize disparities in education, thus negatively impacting Malaysia's national strategy for building capacity in STEM education.

Therefore, a coordinated, integrated strategy for partnership development that invests the appropriate resources to provide access to the STEM-related infrastructure and innovative delivery strategies is critical. Usual solutions include mobile STEM laboratories, digital solutions for learning delivery and community resources as possible solutions to improve equitable access to underserved and hard-to-reach communities. However, while improvements in the sustainable infrastructure will assist with driving improvements in outcomes of STEM education, it will not guarantee improvements in outcomes by itself; it serves to support continued and sustained equitable access to and delivery of STEM education.

#### **6.6. Enhancing Industry-Education Collaboration**

Partnerships among educational organizations and business organizations would create additional benefit by more strongly aligning STEM education with the labor market and increasing the potential for students to prepare for work in their respective fields of study. By providing students with exposure to the practical applications of their learning through "real world" experiences, educational partnerships can enhance student participation in STEM disciplines, improve their un-

derstanding of employment opportunities, and increase their level of motivation. Presently, these partnerships are not prevalent and therefore do not provide enough opportunities for students to engage in experiential learning as educational institutions are not able to participate.

Potential ways to create effective partnerships between educational institutions and businesses include the establishment of formalized relationships (e.g. internships, curriculum co-design, and industry sponsored projects). Additionally, building an organized partnership with local industry sectors will give teachers access to information about industry practices, thereby enhancing the quality of instruction that is delivered in the classroom. Finally, establishing stronger partnerships between industry and education will help to create a more responsive and adaptable STEM system over the long term.

### **6.7. Preparing for Industry 4.0 through Integrated STEM Strategies**

The rapid technological transformations of Industry 4.0 highlight the need for the development of a digitally literate, computationally minded and interchangeably resolved worker. Developing these capabilities is primarily achieved through STEM education, but low participation rates of students point to concerns regarding continued production of a labor-force able to feed Malaysia's growing talent pipeline.

An effective response to this challenge will require a coordinated approach that aligns educational efforts with industry growth, which will benefit students by giving opportunities to observe the numerous ways that STEM education can contribute towards national development and address global challenges through new and emerging industries such as artificial intelligence, renewable energy and smart agriculture.

### **6.8. Directions for Future Research**

Although there are many valuable insights derived from the literature reviewed in the present study, several areas require additional investigation. For example, longitudinal studies that track students from their time in education to when they enter the workforce might result in greater clarity regarding the long-term effects of STEM. An evaluation of the impact of national initiatives would allow for an assessment of the policies' efficacy and thus enable policymakers and educators to improve upon their methods of intervention. Comparative studies within the ASEAN region would also provide researchers with reference points by which they could measure their own successes, as well as possible best practices that might be transferable.

Further research is also needed to identify effective rural STEM models and how new technologies (e.g., artificial intelligence) can be integrated into STEM education. Filling these gaps in research will create an evidence base that provides policymakers and educational leaders with reliable information from which to make informed decisions.

## 7. Conclusions

This review examined the effectiveness of STEM education through a synthesis of recent empirical studies, meta-analyses, and Malaysian case evidence. The findings indicate that STEM education contributes to moderate improvements in higher-order thinking skills, academic performance, and student motivation. These competencies are essential for navigating a technological landscape shaped by automation, digitalization, and interdisciplinary collaboration.

However, the Malaysian context reveals a more complex reality. While STEM initiatives increase students' interest and engagement, enrollment in pure science streams remains significantly below national targets. This participation paradox suggests that improvements in classroom outcomes do not automatically translate into sustained participation. Instead, participation is shaped by a broader constellation of factors, including pedagogical practices, resource distribution, socio-cultural influences, and perceptions of STEM careers.

This review argues that Malaysia's STEM challenge is fundamentally systemic. Addressing declining participation requires coordinated reforms that align policy aspirations with classroom practice, strengthen teacher capacity, expand career awareness, and reduce resource disparities. A multi-layered STEM ecosystem approach provides a useful framework for understanding these interdependencies and guiding future interventions.

While this review focuses on recent literature, further research is needed to examine long-term outcomes, including workforce integration and regional comparisons within ASEAN. Strengthening the evidence base will support more informed policymaking and help ensure that STEM education contributes meaningfully to national development.

Ultimately, the future of STEM education in Malaysia will depend not only on policy ambition but on the collective willingness of educators, communities, and industry to reimagine how learning, innovation, and opportunity intersect.

## Conflicts of Interest

The authors declare no conflicts of interest.

## References

- [1] Abdullah, N., Dahari, Z., Hussin, R. and Abd Aziz, A. (2024) Empowering Malaysia's Youth: Assessing the Impact of STEM Education. *Journal of Entrepreneurship and Business*, **12**, 57-66. <https://doi.org/10.17687/jeb.v12i2.1195>
- [2] Nhat, N.C., Oanh, T.T.K. and Hang, P.T.T. (2024) The Effect of Stem Education on Academic Performance: A Meta-Analysis Study. *International Journal of Learning, Teaching and Educational Research*, **23**, 180-195. <https://doi.org/10.26803/ijlter.23.11.9>
- [3] Ismail, S.N. and Asrah, N.M. (2025) Survey on Exploring STEM Enthusiasm among Secondary School Students in Muar. *International Journal of Advanced Re-search in Education and Society*, **7**, 217-230. <https://mysitasi.mohe.gov.my/uploads/get-media-file?refId=7f4ee8ba-500b-41cc-b933-581034a9a1e7>

- [4] Abdul Rahman, T.F., Zakariah, Z.B., Anuar, N.B., Noh, Z.B. and Abdul Razak, N.B. (2025) The Impact of STEM Activities on Students' Knowledge and Project Development Skills. *International Journal of Research and Innovation in Social Science*, **IX**, 3172-3182. <https://doi.org/10.47772/ijriss.2025.9010257>
- [5] Lu, J., Si, H., Xu, J. and Xu, T. (2025) An Overview of Applications and Trends of STEM for Learning Effectiveness—An Umbrella Review Based on 22 Meta-Analyses. *Educational Research Review*, **48**, Article ID: 100712. <https://doi.org/10.1016/j.edurev.2025.100712>
- [6] Cao, X., Lu, H., Wu, Q. and Hsu, Y. (2025) Systematic Review and Meta-Analysis of the Impact of STEM Education on Students Learning Outcomes. *Frontiers in Psychology*, **16**, Article 1579474. <https://doi.org/10.3389/fpsyg.2025.1579474>
- [7] Yreck, S. (2024) The Effectiveness of STEM Education Programs on Enhancing Critical Thinking Skills among High School Students in Malaysia. *Journal of Asian Multicultural Research for Educational Study*, **5**, 8-16. <https://doi.org/10.47616/jamres.v5i2.531>
- [8] Suherman, S., Vidákovich, T., Mujib, M., Hidayatulloh, H., Andari, T. and Susanti, V.D. (2025) The Role of STEM Teaching in Education: An Empirical Study to Enhance Creativity and Computational Thinking. *Journal of Intelligence*, **13**, Article 88. <https://doi.org/10.3390/jintelligence13070088>
- [9] Martynenko, O.O., Pashanova, O.V., Korzhuev, A.V., Prokopyev, A.I., Sokolova, N.L. and Sokolova, E.G. (2023) Exploring Attitudes Towards STEM Education: A Global Analysis of University, Middle School, and Elementary School Perspectives. *Eurasia Journal of Mathematics, Science and Technology Education*, **19**, em2234. <https://doi.org/10.29333/ejmste/12968>
- [10] Yesnazar, A., Zhorabekova, A., Kalzhanova, A., Abilkhairova, Z., Ortaeva, K. and Jumassaeva, Z. (2025) STEM Education Impact on the Development of Primary School Students' Meta-Subject Skills: An Experimental Study in Kazakhstan. *Frontiers in Education*, **10**, Article 1669765. <https://doi.org/10.3389/feduc.2025.1669765>
- [11] Ministry of Education Malaysia (2013) Malaysia Education Blueprint 2013-2025 (Pre-School to Post-Secondary Education). Ministry of Education. <https://www.moe.gov.my/storage/files/shares/Dasar/PPPM/PPPM%20Laporan%20Tahunan%202023%20%28BI%29.pdf>