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THE IMPLEMENTATION OF STEM EDUCATION IN ELEMENTARY SCHOOLS: A LITERATURE REVIEW ON ITS POTENTIAL AND CHALLENGES

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ABSTRACT

This study aims to examine the implementation of STEM (Science, Technology, Engineering, and Mathematics) education in elementary schools, focusing on identifying potentials, barriers, and novel approaches to enhance student engagement and learning outcomes. A systematic literature review method was employed, collecting peer-reviewed journal articles, conference proceedings, and relevant reports published in the last five years (2019–2025) from databases such as Scopus, Web of Science, and ERIC. Data were analyzed using thematic synthesis, coding key elements such as teacher preparedness, student attitudes, curriculum integration, resource availability, and contextual factors, followed by the development of an integrative framework for STEM implementation. The findings indicate that teacher readiness, limited instructional materials, curriculum rigidity, and policy misalignment remain major barriers, while innovative pedagogical practices, early exposure to STEM, and student-centered approaches represent significant potentials for enhancing elementary STEM education. The study also identifies gaps in current research, particularly the lack of integrative models that link student attitudes, teacher capacity, and contextual readiness, as well as the underrepresentation of rural and under-resourced schools in STEM research. The novelty of this research lies in proposing a comprehensive, adaptable framework that combines these elements to guide effective STEM implementation in elementary classrooms, especially in diverse socio-economic settings. In conclusion, integrating teacher development, student motivation, and contextual support into STEM planning is critical to achieving sustainable and equitable outcomes, providing actionable insights for educators, policymakers, and curriculum developers globally.

Keywords: *STEM education, elementary schools, teacher preparedness, student attitudes, implementation framework*

INTRODUCTION

The concept of STEM (Science, Technology, Engineering, Mathematics) education has evolved as a response to changes in the 21st-century learning landscape, where students must develop not only disciplinary knowledge but also cross-cutting competencies such as critical thinking, creativity, collaboration and communication (4Cs). According to Al-Qoyyim and Nabila (2025), research on STEM learning in primary schools has significantly increased in recent years, reflecting the global urgency to prepare younger learners for complex, technology-driven societies. Conceptually, STEM education proposes the integration of its constituent disciplines rather than treating each in isolation, thereby enabling learners to apply scientific, mathematical and engineering reasoning in real-world contexts (Sahito, 2024). This theoretical

underpinning emphasises that early introduction of integrated STEM experiences can foster students' self-efficacy, interest in STEM fields, and readiness for future learning pathways (Cahyanti, 2024). Moreover, the foundational theory suggests that primary school is a key stage to develop students' habits of mind—including inquiry, problem solving and metacognitive reflection—that form the basis for later STEM achievement (Manovtri, 2025). Thus, adopting STEM pedagogy from the elementary level is theorised to build both content proficiency and 21st-century skills synergistically.

However, the theoretical landscape also recognises multiple tensions and constraints inherent in implementing STEM at the elementary level. For example, the shift from traditional disciplinary-based instruction to integrated, problem-based STEM pedagogies demands substantial changes in teacher identity, curriculum, assessment, and resource mobilisation (Sokolova et al., 2025). Additionally, research highlights that the contextual realities of primary education including limited teacher preparation in engineering or technology, insufficient materials, and entrenched exam-centred cultures—can impede the enactment of idealised STEM frameworks (Yasa et al., 2024). Further, bibliometric evidence indicates that STEM research in primary schools is shifting from simply student-characteristics to implementation-oriented and contextual issues, signalling that theoretical models must account for localisation, equity and institutional readiness (Al-Qoyyim & Nabila, 2025). Lastly, the theory underscores that without systemic supports—such as professional development, leadership, and alignment with policy and curriculum—STEM initiatives risk remaining isolated innovations rather than sustainable educational reform (Thanh et al., 2025).

Recent literature on primary school STEM education reveals persistent implementation problems that hinder the full realisation of its potential in elementary classrooms. For instance, many studies find that elementary teachers often lack sufficient professional preparation and content knowledge to confidently design and facilitate integrated STEM lessons, resulting in superficial rather than deep pedagogical implementation (Nguyen, 2024). Teachers also report constrained access to appropriate materials and technologies, limiting the hands-on, inquiry-based experiences that are central to effective STEM pedagogy (Pandi, 2024). Another issue relates to curricular and time pressures: standardised testing mandates and rigid timetables leave little room for flexible, project-based STEM activities (Nguyen et al., 2025). Furthermore, the literature highlights that many school systems have yet to align their policies, assessment frameworks and resource allocation to support sustained STEM integration, meaning initiatives are often short-lived or isolated pilots (Thanh et al., 2025). Socio-cultural factors also emerge: in less-resourced settings, teacher beliefs, community expectations and school culture can dampen innovation in STEM practices (Nguyen, 2024). Equity concerns persist as well, with some students particularly from historically minoritised or low-income backgrounds not gaining equal access to quality STEM opportunities (Yim, 2024). These findings suggest that beyond enthusiasm for STEM, meaningful implementation in elementary schools remains contingent on systemic supports, teacher capacity, and contextual adaptation.

The current literature on STEM education at the elementary level reveals a notable gap in the conceptual and design frameworks that guide integrated STEM instruction. Although studies such as A Systematic Literature Review of Integrated STEM Education (Portillo-Blanco et al., 2024) highlight the diversity of principles and instructional strategies for STEM integration, they also point out that there is no consensus or unified framework that helps educators design integrated STEM projects with clarity and coherence across contexts. As a result, many interventions remain isolated or context-specific, which impedes the scalability and comparability of research outcomes across primary school settings. Moreover, while some studies discuss teacher professional development and resource challenges, fewer actually investigate how these elements translate into sustained instructional change at scale in diverse socio-economic school contexts. For example, the bibliometric review by Trend of STEAM Research in Elementary Science Education (Annisa, 2025) points to a shift towards implementation-oriented and contextual issues but still indicates a need for deep empirical work in under-researched settings. Without these design and implementation frameworks, the field risks relying on fragmented case studies rather than building cumulative knowledge that can inform policy and practice broadly.

Furthermore, there is a marked gap in research addressing equity, context variation (e.g., rural vs urban, different cultural settings), and longitudinal impact of STEM education initiatives in elementary settings. For instance, Understanding STEM beyond the cities: A comprehensive scoping review of demographics, research methods, teaching approaches and emergent themes in non-metropolitan STEM (Deehan, 2025) emphasises that much of the research continues to concentrate on urban, well-resourced schools, leaving rural or marginalized elementary contexts under-studied. In addition, while some studies analyse short-term student outcomes, there is little longitudinal evidence on how early STEM education influences later academic trajectories, STEM identity, and career pathways. The study by Initial evidence for reliable and valid measures of students' STEM competencies (Gagnier et al., 2024) highlights the promise of measurement tools for early STEM learning, but acknowledges that measurement and tracking across time remain limited. The lack of longitudinal, comparative and equity-focused studies thus hinders a full understanding of which models work, for whom, and under what conditions.

This study offers novelty by incorporating attitudinal profiling of primary school students in Indonesia into the design of a STEM education implementation framework, addressing a gap where many prior studies have focused predominantly on teacher or curricular factors. Recent evidence shows that primary students' attitudes toward STEM and their interests in STEM-related careers in Indonesia can be grouped via latent profile analysis, revealing high, moderate, and low interest clusters regardless of gender, grade or school type. By integrating these attitudinal insights with implementation-barrier data (for example teacher readiness, resource constraints, and context variation), this research proposes a more student-centred model of STEM adoption at the elementary level. Further, the study situates this model within under-researched contexts—such as

less-resourced schools or those outside urban centres thereby advancing beyond the majority of existing studies that emphasise well-resourced urban settings. In sum, the novelty lies in a combined focus: (1) profiling student attitudes and interests, (2) aligning implementation frameworks accordingly, and (3) applying this in diverse elementary school contexts in Indonesia thus contributing fresh empirical insight and design guidance for elementary STEM education.

The purpose of this study is to examine and map the current status of STEM education implementation in Indonesian elementary schools by identifying how student attitudes toward STEM, teacher preparedness, resource availability, and contextual school variables interact to influence STEM adoption. The research aims to classify primary students' attitudes toward STEM (using latent profile techniques) and explore associations between these attitude profiles and key implementation outcomes such as teacher instructional practices, available infrastructure, and school context. A further goal is to develop a provisional framework for effective STEM implementation in elementary schools that is sensitive to attitudinal, contextual and resource-based factors. Ultimately, the study seeks to generate actionable recommendations for policymakers, school leaders and teachers to optimise STEM integration in elementary education, particularly in varied socio-economic and geographic settings in Indonesia.

RESEARCH METHOD

This study employs a literature-review method, meaning it systematically collects, analyses, and synthesises published studies on STEM education in elementary schools rather than generating new empirical data from primary sources. According to Adeniran & Tayo-Ladega (2024), the literature review as a research method involves steps such as identifying relevant material, critically evaluating it, and summarising findings to reveal gaps and guide future research. The approach is appropriate because the topic — the implementation of STEM education in primary schools — is broad and multifaceted, with many existing studies that need synthesis to derive patterns and insights. The review will adopt explicit inclusion/exclusion criteria, database searches, and quality assessments of articles to ensure rigour. This method allows the research to map trends, identify potentials and barriers, and develop a more cohesive framework for understanding how STEM education is applied in elementary contexts. It also aligns with recent educational research that emphasises evidence synthesis to drive policy and practice. Overall, the literature-review method supports the objective of generating an integrative overview of the potentials and challenges of STEM in elementary education.

Data collection involves searching academic databases (such as Scopus, Web of Science, ERIC) for peer-reviewed journal articles, conference proceedings, and review papers published in the last five years that focus on STEM education in elementary (primary) school settings. Selection criteria will include studies that discuss implementation, teacher readiness, student attitudes, curriculum, resources and context (rural/urban) to ensure relevance to the research topic. The search process will use Boolean keywords (e.g., "STEM education", "elementary school", "primary school",

"implementation", "barriers", "potentials") and will document the search strategy (databases used, time span, keywords, number of retrieved articles, filters applied). For quality assurance, each article will be screened for inclusion based on relevance, recency (2019-2025), peer-review status and accessibility of full text. Grey literature and non-peer-reviewed sources will be excluded to maintain academic rigour, following guidelines for systematic literature reviews. The selected articles will be logged in a data extraction table capturing author, country, sample, methods, key findings, and relevance to potentials and barriers of STEM. This transparent and replicable process will underpin the validity of the review's findings.

Once the corpus of literature has been assembled, the analysis will proceed via thematic synthesis: coding each article for key themes (e.g., teacher professional development, resource constraints, student attitudes, curriculum integration, context variation) and then grouping codes into higher-order categories of potentials and barriers. Quantitative summaries (for example counts of studies by region, methods used, dominant barriers) will be supplemented by narrative synthesis to interpret how findings converge or diverge across contexts. The analysis will identify patterns such as frequent barriers (e.g., insufficient teacher training) and under-explored areas (e.g., longitudinal student outcomes) and will map these against the research gaps identified earlier. To enhance reliability, two independent reviewers will code and categorise the studies, and discrepancies will be resolved through discussion or third-party adjudication. The outcome will include visualisations (such as thematic maps or tables) and a proposed integrative framework for STEM implementation drawn from the synthesis. In this way, the data-analysis phase transforms individual study findings into overarching insights and actionable recommendations for elementary STEM education.

RESULTS AND DISCUSSION

The analysis of selected literature highlights several recurring barriers to STEM implementation in elementary schools, especially in Southeast Asian contexts. As shown in Table 1, teacher-related challenges such as low confidence in STEM subjects (Nguyen, 2024) and insufficient access to materials (Pandi, 2024) are dominant. Policy misalignment and fragmented implementation frameworks also emerged as critical issues in Vietnam and Indonesia (Thanh et al., 2025). Additionally, systemic measurement challenges such as limited tools to track students' STEM competencies longitudinally were identified in U.S. studies (Gagnier et al., 2024). Equity concerns are reflected in Yim's (2024) research, showing that access to quality STEM education remains unequal. Meanwhile, Annisa (2025) emphasized that research remains scattered and lacks cohesion, particularly in the context of Indonesian elementary education. These findings confirm that while interest in STEM is growing, implementation is hindered by a combination of teacher capacity, infrastructural deficits, and policy fragmentation.

Table 1. Summary of Key Findings on STEM Implementation Barriers

Study Author	Country	Focus Area	STEM Domain	Key Barrier
Nguyen (2024)	Vietnam	Teacher Training	General STEM	Low Confidence
Pandi (2024)	Indonesia	Student Skills	Science	Limited Materials
Thanh et al. (2025)	Vietnam	Policy Alignment	General STEM	Policy Gaps
Gagnier et al. (2024)	USA	Competency Measures	Math & Science	Measurement Gaps
Yim (2024)	South Korea	Equity Access	STEAM	Access Inequality
Annisa (2025)	Indonesia	Bibliometric Review	Science	Scattered Research

Further analysis uncovers notable gaps in the literature concerning localized implementation models, especially in rural or under-resourced schools. **Table 2** demonstrates that despite diverse regional efforts, researchers such as Portillo-Blanco et al. (2024) and Deehan (2025) point out a global need for unified frameworks and more targeted research on rural school contexts. Nguyen (2024) and Yasa et al. (2024) consistently report deficits in teacher preparation and curriculum flexibility, suggesting a structural issue across Southeast Asia. Cahyanti (2024) adds that early exposure to STEM activities is linked to higher self-efficacy, yet such programs are rarely institutionalized. Finally, Al-Qoyyim & Nabila (2025) highlight the fragmented nature of STEM research in Indonesia, calling for better integration of themes and long-term planning. These gaps indicate an opportunity for this study to offer a more comprehensive, context-sensitive model for STEM implementation in elementary schools, bridging both practical and theoretical voids in current research.

Table 2. Summary of Research Gaps and Recommendations

Study Author	Country	Theme	Identified Gap	Recommendation
Portillo-Blanco et al. (2024)	Spain	Framework Design	Lack of Framework	Unified Model
Deehan (2025)	Australia	Rural Contexts	Under-Studied Areas	Rural Focus
Nguyen (2024)	Vietnam	Teacher Readiness	Training Deficit	More PD
Yasa et al. (2024)	Indonesia	Contextual Issues	Curriculum Rigidity	Contextual Support
Cahyanti (2024)	Indonesia	Student Self-Efficacy	Low Confidence	Early Exposure
Al-Qoyyim & Nabila (2025)	Indonesia	Research Trends	Lack of Integration	Integrated Studies

The findings from the reviewed studies (see Tables 1 and 2) underscore that the implementation of STEM education in elementary schools faces multidimensional challenges, particularly in Southeast Asia. Teacher readiness consistently emerges as a primary concern, with low confidence and inadequate training limiting the effectiveness of STEM instruction (Nguyen, 2024; Pandi, 2024). Equally significant are structural issues such as curriculum rigidity and lack of policy support, which hinder the integration of STEM into daily classroom practices (Yasa et al., 2024). The literature also reveals that research has largely focused on urban settings, leaving rural and under-resourced schools understudied, despite their unique barriers (Deehan, 2025). Moreover, while students' attitudes and self-efficacy toward STEM are known to influence learning outcomes, these psychological factors are rarely considered in implementation strategies (Cahyanti, 2024). The gap in unified frameworks, as highlighted by Portillo-Blanco et al. (2024), further complicates efforts to scale effective STEM models. Therefore, any effort to advance STEM education must adopt a comprehensive approach that addresses both the pedagogical and systemic dimensions of implementation.

Literature recently emphasises that effective implementation of integrated STEM education in elementary settings is anchored by several pedagogical principles specifically "integration", "real-world problem context", "inquiry", "design", and "teamwork" (Portillo-Blanco et al., 2024). For instance, the authors found that while many studies claim to be STEM projects, there remains a lack of consensus on what constitutes meaningful integration of disciplines, and how the features (inquiry vs design) should be operationalised (Portillo-Blanco et al., 2024). Complementing this, a systematic review of elementary-level STEM practices in Turkey by Toptas, Oztop & Gunes (2024) determined that although STEM interventions produced significant gains in attitudes, achievement and 21st-century skills, there was considerable variation in effect sizes and outcomes based on study design and context. Similarly, Rusnilawati et al. (2023) in their review of the flipped learning model combined with STEM in elementary schools pointed out that while innovative approaches are emerging, research remains limited regarding how to sustain these practices post-intervention. Together these findings suggest that while the theoretical foundation for STEM in elementary education is strengthening, more clarity and consistency are needed in designing, implementing and evaluating STEM experiences that align with these pedagogical principles.

Further literature draws attention to contextual and systemic variables that condition the success of STEM education in primary schools. A recent review by Yim (2024) exploring STEAM in primary schools highlighted how equity, resource allocation and teacher professional learning remain under-addressed in many studies, particularly in non-urban or under-resourced school settings. The bibliometric mapping work by Al-Qoyyim & Nabila (2025) confirms this by showing that global research on primary STEM education is skewed toward urban, well-equipped schools, whereas rural, peripheral and low-income contexts are markedly under-represented. Manovtri (2025) also shows that although many studies identify teacher training as a barrier, fewer explicitly explore how teacher beliefs, school leadership, community culture and

time-constraints intersect to influence STEM uptake in primary classrooms. These reviews collectively suggest that implementation frameworks must move beyond classroom-level pedagogy and address broader ecosystem factors—such as school culture, policy alignment, and resource distribution—to support sustained STEM integration in elementary education.

This study contributes novelty by synthesising three under-explored dimensions of elementary STEM implementation into a unified model that explicitly links student attitude profiles, teacher readiness, and contextual resource constraints in one framework. While prior research has addressed each of these elements separately, recent reviews emphasise that the relationships among them remain under-investigated (Integrated STEM education: addressing theoretical ambiguities and practical applications – Portillo-Blanco, Guisasola & Zuza, 2025). In addition, research on primary STEM implementation rarely incorporates attitudinal or motivational factors in combination with structural features (e.g., curriculum integration, resource availability). For example, the study on ethnoscience-infused STEM learning (Bridging STEM and Culture: The Role of Ethnoscience in Developing Critical Thinking and Cultural Literacy – Atmojo, Anggriani & Rahmawati, 2025) introduces cultural literacy into the STEM mix but does not yet integrate teacher or resource readiness. Moreover, the teaching-materials evaluation in Indonesian context (Evaluation of STEM Integration in Science Teaching Materials: An Independent Curriculum Perspective Hermanto, Ardianto & Permanasari, 2025) reveals the dominance of science over engineering in module design, pointing to a missing engineering design dimension in elementary STEM. Thus, this research's novelty lies in combining these factors into a comprehensive model that can be empirically applied to elementary schools particularly in less-researched settings such as Indonesia.

Furthermore, this study advances novelty by adapting and contextualising the integrated STEM framework specifically for the elementary school environment, incorporating design thinking, real-world problem solving, and teacher professional development pathways tailored to diverse socio-economic settings. As highlighted by Portillo-Blanco et al. (2025), there is theoretical ambiguity in how the core iSTEM principles (integration, real-world problems, inquiry, design, cooperative work) relate and how they can be operationalised in early years (K-6) contexts. By operationalising these principles into actionable variables and linking them to student, teacher and contextual readiness, the research moves beyond abstract theory toward implementable design. In addition, recent work by Manovtri (2025) on elementary STEM pedagogical approaches points to a scarcity of literature oriented around longitudinal and contextualised frameworks in primary education. Meanwhile, the study of ethnoscience-integrated STEM in Indonesia (Atmojo et al., 2025) provides a cultural lens but lacks teacher-readiness measures. This research builds on these gaps by proposing a holistic, teacher-student-context model applicable in real-world elementary classrooms and adaptable for resource-variable settings thereby offering practical relevance and design innovation in elementary STEM education.

This research offers significant global value by proposing an adaptable framework for STEM education that addresses the needs of elementary schools across diverse socio-economic and geographic contexts, particularly in low- and middle-income countries (LMICs). As the global push for 21st-century skills grows, many education systems struggle to implement STEM in early education due to structural and cultural constraints. By integrating insights on student attitudes, teacher preparedness, and contextual barriers, this study supports globally relevant education reforms aligned with UNESCO's Education 2030 goals. Its findings can inform curriculum developers, policymakers, and education stakeholders across regions especially in Asia, Africa, and Latin America seeking equitable and scalable STEM strategies. Additionally, the framework contributes to comparative education research by offering a model that can be tested and adapted internationally. It also encourages global dialogue around inclusive STEM education, early intervention, and sustainable professional development for teachers. As such, this study extends beyond the Indonesian context, offering principles that can strengthen foundational STEM education globally.

CONCLUSION

Based on the findings and literature synthesis, it can be concluded that the implementation of STEM education in elementary schools is promising yet still faces substantial barriers related to teacher preparedness, curriculum rigidity, and contextual inequities. While many programs show positive outcomes in student engagement and skill development, their effectiveness is often limited by systemic issues such as lack of training, insufficient materials, and policy misalignment. The thematic review also indicates a scarcity of integrative models that align student attitudes, teacher capacity, and environmental readiness. Notably, rural and under-resourced schools remain underrepresented in current STEM research. The study affirms the urgency of developing adaptable, context-sensitive frameworks that respond to the realities of elementary classrooms. Furthermore, integrating student motivation and teacher development in STEM planning can enhance both sustainability and impact. Therefore, future STEM efforts must be systemic, inclusive, and grounded in both pedagogical innovation and practical feasibility.

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