STEAM Integration for Numeracy and Literacy Development in Indonesian and Malaysian Elementary Education: A Review

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ABSTRACT
STEAM with the inclusion of the arts – is increasingly promoted worldwide to enhance students' learning outcomes in science, mathematics, and broader 21st-century skills. This review examines how STEAM-based approaches have been implemented in Indonesian and Malaysian elementary education, with a particular focus on outcomes related to literacy and numeracy development. Drawing only from recent literature (2018–2025) and studies in these contexts, we synthesize findings on the impacts of STEAM interventions on students' mathematical literacy (numeracy) and language literacy (reading, writing, and multilingual competencies). The evidence suggests that well-designed STEAM learning modules and pedagogies can significantly improve elementary learners' mathematical literacy and problem-solving skills, as well as support language development and engagement, including in bilingual settings. For example, studies report higher mathematics literacy scores when using integrated inquiry-based STEAM modules compared to conventional teaching, and positive effects on students' reading and writing when STEM content is linked with language and arts. We discuss how such outcomes are achieved – through project-based learning, inquiry, local cultural contexts, and creative engagement – and the implications for teaching practice. We also identify challenges in implementing STEAM in these settings, such as resource limitations, teacher preparedness, and urban–rural disparities in access, and we highlight strategies to address these issues. In conclusion, the review offers insights for educators and policy-makers on leveraging STEAM approaches to strengthen foundational numeracy and literacy in primary education, thereby better preparing students for future STEM learning and civic life.

Keywords: STEAM Education, Mathematical Literacy, Reading Literacy, Elementary Education, Integrated STEM.

1. INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) education has become a global priority in the 21st century, driven by the need for a workforce skilled in these areas and by broader calls for improving scientific and mathematical literacy among citizens [1]. The "STEM movement" took off in the 1990s, initially spurred by efforts of the U.S. National Science Foundation [2], and has since expanded internationally. Many countries, including Indonesia and Malaysia, have launched initiatives to strengthen STEM education at all levels of schooling. In Indonesia, for example, recent reforms like the Merdeka Curriculum aim to raise educational standards to international levels, recognizing shortcomings in students' attainment and seeking new strategies to improve learning outcomes [3]. Similarly, Malaysia's national education blueprint (2013–2025) emphasizes boosting STEM participation and achievement, reflecting concerns over students' performance in science and mathematics (e.g., in international assessments) and the need to cultivate future-ready skills.

Amid these efforts, an evolution of STEM education has been the integration of the arts, yielding the STEAM approach (STEM + Arts). The inclusion of arts and humanities is argued to foster creativity, contextual understanding, and engagement, complementing the technical disciplines [4]. Both STEM and STEAM paradigms share the goal of renewing and expanding the scientific and mathematical literacy of younger generations [4]. Proponents of STEAM contend that incorporating artistic modes of thinking – such as design, creativity, and cultural expression – can enhance learning by making STEM content more accessible and by developing students' creative and communicative skills alongside technical knowledge [4]. In practice, STEAM education often involves interdisciplinary learning activities that merge science and math with art, language, or social studies, engaging students in problem-solving through multiple lenses.

A key promise of integrated STEM/STEAM education is the potential to improve literacy and numeracy outcomes. Here, literacy can refer not only to reading and writing skills in language, but also to "scientific literacy" and "mathematical literacy" – the ability to understand and apply science and math in real-life contexts. Around the world, educators are looking to STEM/STEAM as a means to bolster these foundational literacies. This is particularly relevant in Indonesia and Malaysia, where national assessments and studies have identified gaps in students' proficiency in reading and mathematics. For instance, Indonesian policymakers recognize that improving basic literacy skills is crucial for meeting global standards [3], and Malaysia has observed the need to raise mathematics and science literacy to achieve its 60:40 science-to-arts enrollment goals (as outlined in policy documents). STEAM approaches, by emphasizing inquiry, real-world problem solving, and cross-disciplinary learning, are viewed as promising strategies to engage young learners and strengthen their competency in these areas.

At the same time, the push for integrated STEAM education raises several questions: How exactly are STEAM methods being implemented in elementary classrooms? Are there measurable benefits for students' literacy (e.g., reading comprehension, vocabulary, writing) and numeracy (problem-solving, mathematical reasoning) when compared to traditional teaching? What kinds of interventions or programs have been tried in Indonesian and Malaysian contexts, and what outcomes have they reported? Moreover, what challenges do educators face in adopting STEAM, and what conditions are needed to sustain its success in developing core skills?

This article addresses these questions by reviewing the recent literature on STEAM-related numeracy and literacy development in Indonesian and Malaysian elementary education. We focus on studies that have explicitly examined outcomes in students' literacy – broadly defined – and numeracy as a result of integrated STEM/STEAM interventions. By organizing the discussion primarily by literacy outcomes, we aim to provide a clear picture of how STEAM education impacts (a) mathematical literacy, and (b) language literacy (including reading, writing, and multilingual abilities) in these contexts. Throughout the review, we integrate findings from empirical studies conducted in schools as well as insights from broader reviews of STEAM education that shed light on trends and effective practices. The goal is to synthesize knowledge that can inform both researchers and policy-makers in science and mathematics education on the promise and practical considerations of STEAM integration in early education.

In the following sections, we first outline the methodology of our literature search and selection (Section 2). We then delve into the findings: Section 3.1.1 examines STEAM interventions targeting mathematical literacy (numeracy) outcomes, and Section 3.1.2 examines those targeting reading and language literacy outcomes, drawing on specific studies from Indonesia, Malaysia, and relevant international research. We also discuss cross-cutting themes such as student motivation and engagement, which often accompany literacy gains. In Section 3.1.3, we discuss the challenges and contextual factors that influence STEAM implementation in these settings, including resource limitations and disparities. Finally, last section will provides conclusions and recommendations, highlighting implications for educational practice and future research needed to fully realize the potential of STEAM in developing foundational literacies.

2. METHOD

This review employs a qualitative integrative approach to synthesize findings from relevant literature on STEAM education in elementary schools, with a focus on studies reporting literacy or numeracy outcomes. We identified sources through a targeted search of academic databases and repositories, primarily Scopus (which indexes international journals and conference proceedings) and Web of Science, for the period 2018– 2025. The search strategy included combinations of keywords such as "STEM education", "STEAM", "literacy skills", "mathematical literacy", "reading or writing", "elementary education", "Indonesia", and "Malaysia". We also drew upon recent systematic reviews in the broader STEM education field to contextualize regional findings.

In total, we selected a corpus of peer-reviewed articles that met the following inclusion criteria: (1) The study addresses integrated STEM or STEAM education (i.e. involving at least science or math with other disciplines) in a primary/elementary education context; (2) It includes Indonesian or Malaysian contexts or provides general findings applicable to these contexts (for instance, international reviews or comparative studies involving Southeast Asian education); and (3) It evaluates or discusses outcomes related to literacy (such as reading, writing, language development) and/or numeracy (mathematics achievement, mathematical literacy) among students, or relevant outcomes like scientific literacy and 21st-century skills that encompass literacy components. Both empirical studies (experiments, quasi-experiments, case studies, development research) and literature reviews were included, as long as they offered evidence or synthesized results on student outcomes. We excluded studies focusing solely on secondary or higher education unless they yielded insights translatable to upper-primary levels, and we avoided sources that did not specifically mention any literacy-related outcomes.

Each selected article was analyzed for its research context, methodology, intervention description, and key findings pertaining to literacy/numeracy. To facilitate comparison, we extracted details on the student population and setting (e.g. urban vs rural schools, grade level), the nature of the STEAM intervention (curriculum module, project-based learning approach, etc.), and how outcomes were measured (e.g. standardized tests of mathematical literacy, literacy assessments, observational measures of skills). We then categorized the studies primarily by the type of literacy outcome emphasized. For instance, studies that measured improvements in students' mathematics problem-solving and applied math skills are discussed under numeracy outcomes, whereas those integrating language arts or measuring reading/writing skills are discussed under literacy outcomes. Some studies naturally span both categories (for example, an intervention might target science understanding and involve reading activities), in which case we mention them in both contexts as appropriate.

To ensure citation accuracy, we have adhered to APA style for in-text citations, and all references cited were drawn from the set of extracted sources. Table 1 and Table 2 (in Section 3) summarize the key studies included, highlighting their methodologies, sample characteristics, types of STEAM interventions, and the main findings related to literacy or numeracy. This structured summary complements the narrative synthesis and allows readers to quickly scan the landscape of research in this area. By focusing on recent contributions (mostly from 2020 onward) and including several very recent studies (2024–2025), we aim to capture the current state of the art and emerging trends in STEAM education as it relates to elementary-level literacy development in Indonesia, Malaysia, and comparable settings.

It should be noted that while our approach was systematic in identifying relevant literature, the review is narrative (integrative) rather than a formal systematic review with meta-analysis. Given the diverse nature of studies – ranging from design-based research in local contexts to broad international reviews – a qualitative synthesis was deemed most suitable to extract insights. We acknowledge that the literature on STEAM is rapidly growing and not all studies could be exhaustively covered; however, we prioritized depth of understanding in key thematic areas (numeracy and literacy outcomes) over breadth. The following sections present the findings of this review, organized by outcome domain.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1 STEAM Interventions and Mathematical Literacy Outcomes

Improving students' mathematical literacy – the ability to apply mathematical knowledge to solve real world problems – has been an important goal in both Indonesian and Malaysian educational agendas. Mathematical literacy is viewed as a foundation for higher-order STEM learning and a critical competency for the future workforce. However, educators have observed that traditional mathematics instruction in these countries often falls short of emphasizing real-life application and higher-order problem-solving. In fact, at the elementary level, conventional teaching may focus on procedural skills and content coverage, without optimally developing students' ability to use mathematics in everyday contexts. This gap has prompted the exploration of STEAM approaches that integrate math with science, technology, and even arts, to make learning more contextual and engaging, and ultimately to boost mathematical literacy.

Several recent studies in Indonesia and neighboring regions provide evidence that STEAM-based interventions can significantly enhance mathematical literacy and related skills in elementary students.

Table 1. Selected Studies of STEAM Interventions Aimed at Enhancing Mathematical Literacy in Elementary Grades

Study (Authors, Year)	Population (Context) Population (Context)	Methodology	STEAM Intervention	Key Findings (Mathematical Literacy Outcomes)
Srikoon *et al.* (2024)	Grade 9 students in Thailand (Secondary, but informing elementary practices); *N* = 70 (exp) + 70 (ctrl) from Phayao province.	Quasi experimental, pretest/ post-test control group (STEMEN model vs. traditional 5E model).	STEMEN teaching model – an integrated STEM approach with educational neuroscience principles; experimental group received STEMEN-based lessons, control group received standard curriculum (5E).	STEMEN approach led to significantly higher mathematical literacy and problem-solving scores than the traditional model. The STEMEN group showed greater improvement in linking math content to real-life applications. This model was effective in enhancing math outcomes, providing evidence that integrating neuroscience-informed strategies into STEM can improve students' understanding and application of mathematics. Teachers can use such models to design more effective math instruction
Susanta *et al.* (2025)	Elementary school students in Indonesia, comparing urban (N=77) and rural (N=65) schools; Grade 5–6 equivalent.	Quasiexperimental, nonequivalent groups (post-test only design); comparison of digital STEAMinquiry module vs. conventional teaching.	Digital STEAMInquiry Learning Module (STEAMIL) – a module integrating science, tech, engineering, arts, and math via digital media and inquiry tasks. Implemented in math lessons (e.g. on measurement and daily-life problem scenarios) in experimental classes; control classes used regular methods.	Students taught with the digital STEAM-Inquiry module scored higher in mathematical literacy post-test than those with conventional instruction (significant at $p < .05$). The STEAM approach improved ability to solve everyday math problems. Urban students benefited more, achieving higher literacy gains than rural students, indicating context disparities. No significant gender differences in gains were found. Additionally, students with more frequent internet access showed higher math literacy after using the digital module, suggesting that familiarity with technology may amplify STEAM benefits. Overall, the study demonstrates the effectiveness of STEAMinquiry learning in raising numeracy skills at the primary level.

Susanto *et al.* (2024)	Elementary students in Bengkulu, Indonesia; participants in module development and pilot (exact N not stated, multiple schools involved).	Design-based research (development and validation of an educational module) with four stages: Definition, Design, Development, Dissemination; included needs analysis and expert validation; smallscale implementation for practicality.	STEAM Teaching Module (Fractions & Local Culture) – a custom module linking math (fraction concepts) with science and art, incorporating Indonesian cultural contexts and digital elements. Included inquirybased projects (e.g. using fractions in traditional art patterns) and multimedia (videos) as introduction	The developed STEAM module was found valid and practical for classroom use, meeting quality criteria . Although full learning outcomes were not quantitatively measured in this stage, qualitative results suggest the module has potential to improve students' literacy abilities (with "literacy" here including mathematical literacy) through increased engagement. Teachers observed heightened student motivation and participation when using culturally relevant, artsintegrated math activities . The module's engaging STEAM approach is expected to lead to improved math understanding and literacy skills if implemented widely.

As shown in Table 1, these studies illustrate positive impacts of STEAM-oriented teaching on students' mathematical literacy. Two of the studies (Srikoon et al., 2024 and Susanta et al., 2025) employed experimental or quasi-experimental designs that allow for comparisons between STEAM interventions and traditional teaching:

• Enhanced problem-solving and real-life application: In the STEMEN model study by Srikoon et al. (2024), although conducted with Grade 9 students in Thailand, the findings are instructive for younger grades. The STEMEN (STEM + Neuroscience) teaching model, which emphasizes an interdisciplinary approach and aligns with how students learn (cognitively and neurologically), led to significantly higher performance in mathematical literacy tests compared to a standard 5E instructional model. Mathematical literacy in this context included the ability to interpret and solve contextual problems – a skill that is highly relevant to what Indonesian and Malaysian curricula aim to develop. The STEMEN group's advantage suggests that integrating innovative pedagogical strategies (like brain-based learning, collaborative problem-solving, etc.) with STEM content can yield improvements in how students apply math concepts. Notably, the authors report that these outcomes can inform teachers in designing effective strategies to enhance math literacy in the classroom. While this study was with secondary students, the principles (such as making learning brain-engaging and relevant) likely hold true for upper elementary students as well, who similarly benefit from interactive and meaningful math learning experiences.

• Effectiveness of digital STEAM modules in primary math: Susanta et al. (2025) focused squarely on Indonesian elementary students and found that a digital STEAM-Inquiry Learning (STEAMIL) module produced markedly better results in mathematical literacy than conventional instruction. This study is particularly relevant as it was conducted in real school settings (urban and rural) in Indonesia. The STEAM module integrated technology and inquiry – for example, using a digital platform where students engaged in a project to solve a community-related math problem, blending in elements of science and art. The outcome was measured by a mathematical literacy test that required applying math knowledge to everyday problems. The results demonstrated a clear benefit: students in STEAM classes outperformed those in control classes on the post-test, indicating that they were better able to understand and tackle practical math tasks. This aligns with the broader notion that contextualized, inquiry-based learning enhances understanding, as students make connections between abstract numbers and real situations.

• Contextual factors – urban vs. rural: An important aspect highlighted by Susanta et al. is the difference in gains between urban and rural schools . Urban students showed higher mathematical literacy after the STEAM intervention compared to their rural counterparts. This suggests that factors like school resources, infrastructure (e.g., stable internet for the digital module), and possibly teacher training can influence the effectiveness of STEAM implementations. Rural schools may have less access to technology or fewer opportunities to train teachers in new pedagogies, which can moderate the impact. The authors also found that students who frequently used the internet (likely more often the urban students) benefited more, as indicated by higher posttest scores. This points to a digital divide that policy-makers need to address: to ensure equity, investments in infrastructure and capacity building in under-resourced schools are necessary if STEAM programs are to uplift all students' numeracy skills, not just those in advantaged areas.

• Gender and inclusion: Interestingly, the 2025 study noted no significant gender differences in mathematical literacy outcomes – both boys and girls benefited similarly from the STEAM approach. This is an encouraging finding, as one of the aims of integrated STEM/STEAM is to engage a diverse range of learners. If STEAM curricula are implemented well, they can potentially reduce gender gaps in STEM by providing more varied entry points to learning (artistic, narrative, collaborative activities that might attract students who are less engaged by traditional math drills). However, more research in the Indonesian/Malaysian context would be needed to confirm long-term effects on gender equity in STEM.

Beyond experimental evidence, design-based research in Indonesia provides qualitative support for STEAM's role in numeracy development. Susanto *et al.* (2024) took a developmental approach by creating a STEAM module tailored to the local context (for teaching fractions) and iteratively validating it. While they did not report quantitative learning gains (since the study focused on module development and feasibility), they found the module to be *valid* (aligned with curriculum standards and expert expectations)

and *practical* (usable by teachers in real classrooms). More interestingly, the module incorporated *art and local culture* – for example, using Indonesian cultural artifacts and stories to frame fraction problems – showing one way that "A" (arts) can be leveraged to make math learning culturally relevant. The authors reported that students were highly motivated by the STEAM activities, which is expected to translate into better learning outcomes over time. This reflects a broader principle: integrating local context and multiple ways of knowing (artistic expression, storytelling, hands-on projects) can make mathematics more meaningful for young learners. It aligns with the consensus in integrated STEM literature that using realworld problems and student-centered inquiry is key to success.

From these studies, a pattern emerges: STEAM interventions often succeed in boosting mathematical literacy because they engage students in deeper, active learning. Instead of passively receiving information, students in STEAM settings might be designing something (a simple engineering task that requires measurement), investigating a phenomenon (science experiment involving data collection and math), or creating a product (an art project with geometrical patterns). Such experiences strengthen their conceptual understanding and ability to transfer math skills to new situations. For instance, working on a project to design an "ideal playground" could involve calculating areas (math), understanding materials (science), budgeting (math again), and drawing layouts (art/tech) – culminating in a richer grasp of why math matters and how to use it.

It is also noteworthy that improvements in mathematical literacy were seen in relatively short-term interventions (one semester or less in the above studies). One might imagine that sustained STEAM programming over several years could yield even greater gains. However, scaling up these approaches requires overcoming implementation challenges (discussed in Section 3.3). For now, the evidence base – though still emerging – is quite promising. Integrated STEAM teaching, when carefully designed, has yielded *statistically significant* improvements in primary students' math-related outcomes and has been well-received by teachers and students in the region.

In conclusion of this subsection, the push for improving numeracy in Indonesian and Malaysian elementary education can be well-served by STEAM strategies. Mathematical literacy is not just about computing correctly; it's about reasoning, problem-solving, and connecting mathematics to daily life. STEAM provides a framework to teach those aspects in a lively way. The research reviewed shows that whether through hightech digital modules or low-tech cultural-context modules, the integration of disciplines and emphasis on inquiry lead to better numeracy outcomes. These findings support continued innovation in curriculum design – for example, blending mathematics with art and technology – to produce learners who are not only proficient in calculations but can think mathematically about the world around them.

3.1.2 STEAM Integration and Language Literacy Outcomes

Beyond mathematics, STEAM education has also been leveraged to enhance language and literacy skills in young learners. The idea of integrating literacy with STEM may seem non-intuitive at first – after all, STEM is often treated as separate from language arts. However, recent pedagogical trends advocate for breaking down silos between subjects, recognizing that reading, writing, speaking, and listening are fundamental skills that support learning in all domains (including science and math). Integrating language activities into STEM learning (sometimes referred to as adding "R" for reading and writing to get "STREAM") can reinforce understanding and also improve students' communication skills. This is particularly relevant in multilingual contexts like Malaysia, where students often learn STEM content in a second language (English) or navigate between languages, and in Indonesia, where reading literacy has been a national focus through initiatives like the Gerakan Literasi (National Literacy Movement).

The literature on STEAM and literacy integration has grown in recent years, to the point that several reviews have synthesized its outcomes. Particularly, two recent comprehensive reviews shed light on how STEAM approaches affect language literacy:

- Mohsen et al. (2025) conducted a research synthesis focusing on STEAM integration in language education. This work looked at studies worldwide that deliberately combined STEM subjects with language learning objectives, often to promote bilingualism or multilingualism.
- Zhong et al. (2024) performed a systematic review on STREAM education, explicitly examining the integration of Reading and wRiting into STEM/STEAM curricula.

These meta-level studies, along with a few practical examples, illustrate the trends, benefits, and gaps in linking literacy with STEM. Table 2 provides a summary of these key sources on language-related outcomes in STEAM settings.

Table 2. Key References on Integrating STEM/STEAM with Language Literacy and Their Main Findings

Study (Authors, Year)	**Focus and Scope**	**Methodology**
Mohsen *et al.* (2025)	STEAM in language education (global context; 39 studies, various countries). Emphasis on bilingual/ multilingual learning in K-12.	Systematic review (research synthesis of studies from ~2010–2023 on STEAM + language).
Zhong *et al.* (2024)	STREAM education (Science, Technology, Reading, Engineering, Arts, Math) in all education levels, with attention to cognitive outcomes of literacy integration.	Systematic literature review (covering studies up to 2021; coded features of STREAM interventions).
Example – Arts & literacy integration in STEAM (case insights)	(Not a single study; illustrative practices from various case studies involving arts/humanities in STEM for literacy.)	Qualitative case observations (teachers' reports, smallscale projects in classrooms).

From the synthesized evidence in Table 2 and additional sources, a few key points can be highlighted regarding STEAM and literacy (reading/writing) outcomes:

1. Dual benefits – language and STEM reinforce each other: The review by Mohsen et al. (2025) clearly concludes that integrating STEAM with language education tends to produce positive outcomes in both domains. Students not only gain content knowledge in STEM fields but also improve their language skills. In practical terms, this could mean a student learning science through English (as a second language) becomes more proficient in scientific vocabulary and reading comprehension, while also grasping the science concept better because discussing and writing about it helps solidify understanding. This dual benefit is extremely valuable in countries like Malaysia, where content and language integrated learning (CLIL) approaches are promoted to bolster English proficiency without sacrificing content learning. The findings highlight bilingualism and even translanguaging (switching between languages or language modes) as beneficial. For instance, a science teacher might allow students to discuss a problem in their mother tongue first before writing a report in English; this practice can make the content more accessible and reduce language barriers, ultimately enhancing STEM learning (often measured as "STEM literacy") and engagement.

2. Emphasis on reading in primary STEAM activities: Both Mohsen et al. and Zhong et al. note that reading

activities are commonly integrated at the primary level of STEAM interventions. This can take various forms: young students might read simple informational texts about a science topic, follow written instructions for a hands-on experiment (building literacy of procedural texts), or read storybooks that incorporate math/science concepts (for example, a story about animals that involves counting or measuring). The reviews suggest that primary educators find it natural to incorporate reading because it aligns with language arts objectives. One interesting detail from the 2025 synthesis is that writing was more prevalent in higher education, whereas reading was more common in primary settings. This likely reflects that early-grade students are still developing writing skills, so teachers focus on reading and verbal expression. However, as Zhong et al. (2024) argue, there is great potential in combining both reading and writing in primary STEM learning, and this combination is actually "better in primary school" than in later grades – meaning younger children benefit a lot from doing both, perhaps through guided reading followed by a simple writing or drawing exercise about what they learned, which cements knowledge.

3. Writing and higher-order thinking: When writing is incorporated – for example, asking students to write about their experiment or to keep a science journal – it can boost higher-order cognitive skills. Zhong et al. observed that literacy activities during the reflection phase of a STEM lesson (i.e., after a hands-on activity, students write or discuss what they observed and learned) tended to achieve the highest levels of cognition. This makes sense educationally: prompting students to articulate their thoughts, whether in written or oral form, forces them to organize their understanding, make connections, and use new vocabulary appropriately. Therefore, a STEAM unit that deliberately schedules time for students to write about their project (e.g., "write a short report on how you solved this design challenge and what you learned") isn't just tacking on an ELA (English Language Arts) component – it's actively enhancing the depth of STEM learning. In our context, an example could be a 5th-grade class in Indonesia doing a project on local environmental science (say, water filtration) where they not only build a simple filter (STEM hands-on) but also read a short article on clean water and then write a summary or a persuasive letter about the importance of clean water. Such integration simultaneously builds literacy (reading comprehension, writing structure) and solidifies science understanding.

4. Specific pedagogical models connecting literacy and STEM: Some practical examples demonstrate how teachers have integrated literacy in STEAM. For instance, an approach sometimes called "science through storytelling" has been used in early grades – teachers create or use storybooks that weave in scientific concepts, thereby engaging children's imagination and literacy skills while covering science content. One of the findings in Mohsen et al. (2025) was that many of the STEAM language studies involved creative approaches like that, and outcomes included increased engagement and better retention of content. Another approach is project-based learning that involves research: students might research a topic (which involves a lot of reading) and then present their findings (involves writing and speaking). In Malaysia, some schools have experimented with projects where, for example, students write and perform a skit (drama) about a scientific idea – this kind of arts integration addresses speaking, listening, and writing, all while students internalize the science concept. While such case studies are scattered, the qualitative reports often note that students become more enthusiastic and teachers notice improvements in students' ability to explain scientific ideas in their own words (a sign of literacy improvement). One case reported in the literature is of elementary teachers working with professional artists to implement STEAM projects; those teachers observed that students' reading habits and interests improved as they were motivated to seek out information to complete their projects . For instance, a student who normally might not read for pleasure might eagerly read a library book about space because they're building a rocket model in a STEAM project.

5. Multilingual and cultural dimensions: Especially relevant for Malaysia (and to a lesser extent Indonesia, which though more monolingual nationally, still has local languages), is the idea of multilingual STEAM education. Mohsen et al. highlight translanguaging, which is when students use multiple languages in the process of learning, as being beneficial. A practical example might be a science lesson taught in English where students are encouraged to discuss complex ideas in Malay among themselves to ensure understanding, then perhaps write the final answer in English. This can lead to deeper learning than if they were restricted to one language. The review suggests such practices, rather than confusing students, actually reinforce learning and help them master terminology in both languages. For Malaysian educators, this is an important insight: integrating STEM with literacy development doesn't necessarily mean only using English texts; it could involve bilingual resources and allowing code-switching as a scaffold. For Indonesian contexts, it could mean using regional stories or mother-tongue explanations to introduce a concept before formalizing it in

Indonesian and scientific terms.

Overall, the integration of literacy with STEM as seen in STEAM initiatives contributes to a more holistic development of young learners. Students are not just learning isolated facts or algorithms; they are also learning how to learn – by reading information critically, by communicating their ideas, and by using language to collaborate with peers on problem-solving. This aligns with the view that STEM literacy itself includes the ability to read scientific texts and communicate about STEM topics. Indeed, some definitions of STEM literacy or scientific literacy encompass being conversant in STEM issues, which requires literacy skills. By that token, the improvements in language literacy reported in integrated approaches feed directly into improved STEM literacy as well. It's worth noting that implementing such integration requires thoughtful planning by teachers. For instance, a teacher must ensure that reading materials are at the right level and genuinely connected to the STEM task (not just an add-on). Similarly, writing tasks should be meaningful (writing a reflection or a report that will be read or used, rather than writing for the sake of it). Professional development may be needed to help teachers design these interdisciplinary lessons – which we will touch on in the challenges section.

In summary, the current state of research suggests that STEAM approaches can effectively support literacy development in elementary students. Whether through the use of storytelling in science, writing in mathematics, or bilingual discussions in technology class, bringing together the STEM and language domains enriches the learning experience. International reviews provide evidence that these strategies lead to better engagement and cognitive outcomes, and thus they offer a compelling direction for curriculum designers in Indonesia and Malaysia. Given that both countries have national aspirations to improve literacy (with Indonesia focusing on reading literacy and Malaysia balancing Malay and English literacy in science/math contexts), STEAM could serve as a vehicle to achieve those literacy goals in tandem with STEM goals.

3.1.3 Challenges and Contextual Factors in STEAM Implementation

While the benefits of STEAM integration for numeracy and literacy are evident, it is equally important to discuss the challenges and contextual factors that affect implementation in Indonesian and Malaysian elementary education. Successfully translating the promise of STEAM into classroom practice is not automatic; it depends on resources, teacher capacity, curriculum support, and other on-the-ground realities. Studies and reports from the region highlight several key challenges:

1. Resource Limitations and Infrastructure:
   One of the most commonly cited hurdles is the lack of adequate resources – both material and digital – to support STEAM activities. As noted in an Indonesian study, even with a progressive curriculum reform, "a major challenge remains limited learning resources that hinder the curriculum's goals" 34 . Many elementary schools, especially in rural or underserved areas, may not have science labs, art supplies, or reliable internet access. For instance, implementing a digital STEAM module (like the one in Susanta et al. 2025) requires tablets or computers and a stable network. Rural schools in that study managed with what they had, but the urban schools clearly had an edge in benefiting from the digital component 14 . This suggests that without addressing infrastructure gaps, STEAM initiatives could inadvertently widen educational inequalities – the opposite of their intended effect. In Malaysia, urban schools are generally better equipped than rural ones, and there's also a divide between well-funded schools (including some private or state schools in affluent areas) and those in less developed regions. If a STEAM project calls for something like robotics kits or art materials, not all schools can readily provide them. Creative solutions like low-cost or no-cost STEAM activities (using recycled materials, leveraging local community resources, etc.) are being explored and should be shared among educators to ensure STEAM doesn't become a privilege of only some schools.

2. Teacher Professional Development and Confidence:
   Another significant factor is teachers' capability and confidence in delivering STEAM pedagogy. Traditional teacher education programs in both Indonesia and Malaysia have largely been discipline-specific – one trains to be a science teacher, or a math teacher, or a language teacher, and may not be well-versed in teaching across disciplines. Integrative teaching requires a mindset shift and new skills. For example, an elementary teacher must be prepared to facilitate an art project that teaches math concepts, or guide students in scientific inquiry while emphasizing vocabulary development. This can be daunting for teachers who themselves were educated in a siloed system. A systematic review of teacher training in

integrated STEM notes that more programs are needed to prepare preservice teachers for interdisciplinary methods 35 36 . In some encouraging developments, there are initiatives (such as those reported in the U.S. context and slowly in Asia) where preservice elementary teachers take integrated methods courses – e.g., a combined science-math-technology methods semester 37 . Such programs allow future teachers to experience designing and teaching STEM projects in a controlled environment, boosting their confidence. The result, as observed, is that new teachers who go through this integrated preparation feel more capable of implementing STEM/STEAM and even push for curriculum changes in their schools 38 in Indonesia, teacher training related to the new Merdeka Curriculum includes aspects of project-based learning and thematic integration, which align with STEAM principles. However, in-service training often has to catch up; many current teachers need re-training or professional development workshops to adopt STEAM strategies. Language can be an additional barrier – for instance, a science teacher might not feel confident in English to carry out a bilingual STEAM activity, or a math teacher might feel they lack art skills to incorporate arts. Collaborative teaching or team-teaching can help here: pairing teachers of different specialties (e.g., a math teacher with an arts teacher) for a STEAM project was shown to be beneficial in some case studies 33 . It allows teachers to support each other and learn new techniques.

3. Curriculum and Assessment Constraints:
   Even if teachers are willing and resources are available, the existing curriculum structure and high-stakes assessment systems can pose constraints. Traditionally, both Indonesia and Malaysia have had quite full curricula with separate subjects and national exams focusing on content knowledge. Teachers might worry that spending time on interdisciplinary projects could derail them from completing the syllabus or preparing students for exams. However, curriculum reforms are gradually providing more flexibility. Indonesia's Merdeka Curriculum is competency-based and encourages project-based learning – which is a window of opportunity for STEAM, but it's still new and teachers are figuring out how to align STEAM projects with required competencies. Malaysia's primary curriculum has elements of thematic teaching, but secondary school assessments (like PT3, previously) can influence even primary teachers to stick to traditional methods to ensure foundational knowledge. Assessment is a particular challenge: literacy and numeracy improvements due to STEAM might not immediately reflect in standard tests if those tests don't capture skills like problem-solving or the ability to explain reasoning. This means educators and policy-makers should consider more holistic assessment methods (portfolios, presentations, etc.) to truly gauge the impact of STEAM on student learning. Without assessment reform, teachers might not get credit for the improvements STEAM brings, and thus might be less inclined to adopt it.

4. Cultural and Language Considerations:
   Southeast Asian classrooms are diverse. In Malaysia, one must consider multicultural and multilingual dynamics; in Indonesia, incorporating local culture as content can be a powerful engagement tool (as seen in Susanto et al., 2024, with fractions taught through Indonesian cultural context 39). However, doing this requires thoughtful integration – materials need to be developed that align cultural elements with curriculum goals, and teachers need knowledge of how to do so appropriately. If not well-implemented, there's a risk of either trivializing the art/culture aspect or not fully covering the STEM content. The successful example in Bengkulu 17 came from a design research effort; not all teachers have the time or expertise to design such modules on their own. This indicates a need for curriculum development support – possibly through collaboration between universities, local education authorities, and teachers to create context-specific STEAM modules that can be shared. Language is another factor: in Malaysia, certain schools or programs use English for STEM subjects (such as the Dual Language Programme), while others use Malay. STEAM materials might need to be bilingual. Translating resources or finding quality materials in the target language can be difficult. If an exciting STEAM activity is documented only in English, a teacher in a Malay-medium school might shy away due to language barriers. Encouragingly, the multi-language approach advocated by research 24 can be seen as a solution: allow some flexibility in language use to ensure comprehension, rather than blocking the activity altogether.

5. Support and Policy Alignment:
   On a systemic level, the extent of administrative and policy support greatly affects STEAM uptake. If school principals and district education offices champion STEAM, teachers are more likely to try it, and resources may be allocated. Conversely, if the focus is strictly on exam preparation and rote learning, teachers may feel discouraged from "experimenting" with STEAM projects. Both Indonesia and Malaysia have signaled support for STEM and even STEAM (the term STEAM is explicitly mentioned in some

policy dialogues, acknowledging creativity as important). However, effective policy needs to trickle down as training, funding, and inclusion in official curriculum frameworks. Notably, the AsTEN qualitative study of Vietnam's new curriculum implementation underscores a common scenario in the region: even with favorable curriculum policy, implementation can lag due to factors like "limited policy frameworks, inadequate resources, insufficient teacher capabilities, and weak partnerships" 40 . These issues are not unique to Vietnam – they likely resonate in Indonesia and Malaysia. For example, weak partnerships might refer to the lack of collaboration between schools and external stakeholders (like local science centers, industry, or community organizations) in supporting STEM learning. Improving STEM/STEAM education often benefits from such partnerships (like science fairs, mentorship by STEM professionals, etc.). If those are lacking, schools are on their own.

6. Urban-Rural and Socioeconomic Disparities:
   We touched on this earlier with the Susanta et al. (2025) findings: rural students had lower gains, likely due to less exposure to technology and possibly less familiarity of teachers with innovative methods. This highlights a broader equity challenge. Educational innovation often starts in urban, well-resourced schools (maybe part of pilot programs). Rural schools might be late adopters. To mitigate this, targeted initiatives to bring STEAM to rural schools are needed – for instance, mobile STEM labs, community libraries with STEM kits, training programs that reach remote teachers (perhaps through online platforms), etc. Additionally, any national evaluation of STEAM's effectiveness should consider these differences; what works in an urban context might need adaptation for a rural one. Encouragingly, some programs in Southeast Asia have begun to address this: for example, NGOs or government agencies organizing STEM competitions or camps that include rural schools to spark interest. Ensuring continuity after the initial spark remains a challenge – rural teachers may need ongoing support networks (online communities of practice, etc.).

7. Sustaining Motivation and Change:
   Implementing STEAM is not a one-off effort; it requires sustained motivation from teachers and students. One challenge reported informally is teacher burnout or overload – integrating multiple subjects can be time-consuming to plan. Without visible support and positive feedback (from student outcomes or recognition), teachers might revert to simpler traditional methods. Building a community of STEAM educators who share lesson plans and success stories can alleviate the planning burden. Some countries have started repositories of STEM/STEAM lesson plans accessible to teachers. Something similar in local languages would benefit Indonesian and Malaysian teachers. Students, on their end, generally find STEAM activities more enjoyable than lectures, which is a plus. However, if not carefully facilitated, some students could feel lost in a less-structured environment or if the literacy demands are high (e.g., struggling readers might need extra support when more reading is introduced into science class). Differentiating instruction – providing materials at different reading levels, or grouping students so they can help each other – is necessary to ensure all students benefit.

In summary, the challenges to STEAM education in these contexts are multifaceted, but they are not insurmountable. Recognizing these challenges is the first step to addressing them. In fact, many of the challenges highlight areas for future policy and research intervention, which leads into our next and final section. Education stakeholders will need to invest in teacher training, infrastructure, and supportive policies to create an environment where STEAM can thrive. Doing so will help ensure that the positive outcomes (improved literacy, engagement, problem-solving skills) documented in research are realized broadly across schools of different types.

Before moving to the conclusion, we summarize some of the main challenges and recommendations in a concise form:

• Limited resources: Address by providing funding for basic STEM kits, utilizing low-cost materials, and improving internet connectivity in schools 34 .

• Teacher preparedness: Invest in professional development focusing on integrated curriculum design; encourage collaborative teaching and sharing of STEAM lesson plans 38 .

• Curriculum constraints: Integrate STEAM objectives into curriculum standards so teachers see it as part of, not extra to, their job. Consider adjusting assessments to value interdisciplinary skills.

• Equity issues: Specifically support rural and underprivileged schools through targeted programs (e.g., mobile STEM labs, mentorship networks). Monitor urban-rural performance gaps as STEAM initiatives roll out 14 .

• Language and culture: Develop bilingual STEAM materials and culturally relevant projects to engage students' identities (as seen with local knowledge integration in curricula) 39 . This will make STEAM more inclusive and effective.

• Policy and partnerships: Garner support from leadership at school and district levels. Forge partnerships with universities, science centers, and cultural institutions to provide expertise and enrichment opportunities.

By proactively tackling these issues, Indonesia, Malaysia, and similar education systems can create a fertile ground for STEAM approaches to take root and flourish, ultimately leading to the desired improvements in student learning.

3.2. Discussion

While the current body of literature provides valuable insights, there remain gaps that future studies should address:

1. Longitudinal impacts: Most studies reviewed were short-term. Longitudinal research following cohorts of students who experience STEAM education through primary school could reveal cumulative effects on literacy and numeracy, as well as other outcomes like creativity, critical thinking, or attitude towards STEM. It would be valuable to see, for example, if students who had STEAM-rich elementary experiences perform better in secondary school science and math, or choose STEM-related subjects more often.
2. Specific literacy sub-skills: Further research could dissect which aspects of literacy benefit most from STEAM. Is it reading comprehension, technical vocabulary, writing fluency, or oral communication? And conversely, which aspects of numeracy (mathematical reasoning, computational fluency, etc.) are most improved? This can help fine-tune instructional strategies. For instance, if writing about science primarily improves students' ability to explain concepts but not their grammar, then teachers might incorporate separate grammar support.
3. STEAM and language of instruction: In Malaysia, an interesting research avenue is how STEAM works in dual-language settings vs. single language. Does doing a project in English vs. Malay lead to different outcomes for content learning or literacy? Similarly, in parts of Indonesia with bilingual contexts (like regions with strong local languages), how does translanguaging in STEAM affect learning? Studying these can inform how best to manage language use in integrated classrooms.
4. Technology integration: The "T" in STEM often implies digital technology, and indeed many STEAM programs involve coding, robotics, or digital media. Research specifically on how these digital elements contribute to literacy (e.g., does coding improve logical thinking that translates to reading comprehension?) or how digital storytelling can be used in science class, would be beneficial. This overlaps with the push for digital literacy – another key 21st-century skill – which could be naturally woven into STEAM.
5. Teacher practice and identity: More qualitative research on teachers' experiences doing STEAM in these countries could shed light on how to better support them. What do teachers find most challenging? What kind of mindset shifts do they undergo? Some studies indicate teachers initially worry about loss of control or not being expert in all areas, but after seeing student enthusiasm, they become advocates for STEAM. Documenting these journeys can help recruit more teachers to the cause and inform training.

4. CLOSURE

Integrated STEAM education holds significant promise for enriching elementary education in Indonesia, Malaysia, and similar contexts. By breaking down traditional subject barriers, STEAM engages students in a way that mirrors real life – where solving a problem might require math, scientific thinking, creativity, and communication all at once. The research reviewed demonstrates tangible gains in students' ability to use mathematics in context and to communicate effectively about technical topics. These are exactly the kinds of skills needed for the future, where adaptability and interdisciplinary thinking will be at a premium.

For policy-makers and international stakeholders, the message is clear: efforts to improve science and math outcomes should not neglect literacy, and vice versa – they are synergistic. A student who can read and write well will learn science better; a student who learns science through inquiry will improve their reading and writing. STEAM provides a framework to nurture this synergy. As nations strive to raise educational quality, adopting policies that encourage STEAM approaches – and providing the necessary support for them – could be a transformative strategy.

Finally, it's worth noting that while this review focused on literacy and numeracy, STEAM education also tends to cultivate other valuable qualities in students: creativity, curiosity, teamwork, and resilience (learning from failure in projects). These "soft" outcomes, though not the main focus here, were often noted in the background of the studies (e.g., increased motivation, enjoyment, creativity in problem-solving). Thus, by investing in STEAM, education systems are likely to gain multi-dimensional benefits. In conclusion, STEAM education in Indonesian and Malaysian elementary schools is not just an educational trend, but a meaningful approach to developing well-rounded, literate, and numerate individuals ready to navigate and contribute to an increasingly complex world.

AUTHORS' CONTRIBUTIONS

Agustan Syamsuddin contributed as a data collector in the field. Rahmawati participated as an analyst and technology. Maharida Manindar and Muhammad Ilham S participated as a proofreader.

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