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STEAM+X in Mathematics Education: A Systematic Literature Review

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ABSTRACT

This study analyses how the STEAM+X framework has been implemented in mathematics education. The "X" component represents additional disciplines beyond the traditional STEAM fields, such as culture, history, and architecture. The systematic literature review (SLR) follows the PRISMA protocol. The initial search returned 350,190 documents, but only one article met the rigorous inclusion criteria focused explicitly on STEAM+X in mathematics education. This finding underscores the topic's novelty and the need for further research. The selected study highlights the integration of geometry, digital and physical technologies (e.g., GeoGebra, AR/VR, 3D printing), and educational levels, including high school and teacher education. The analysis reveals limited implementation across countries and a lack of diversity in content areas. These results call for expanded investigations into STEAM+X practices incorporating broader mathematical domains, varied cultural contexts, and more inclusive educational levels.

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1. INTRODUCTION

For many individuals, mathematics is a significant academic challenge [1], [2], [3], [4]. This challenge arises because of the abstract nature of mathematical concepts, which are full of formulas and symbols [5], [6] and require special talents [7], [8], making them difficult to understand. Various studies [9], [10], [11] and universities [12] in many countries, including Indonesia, support this opinion by demonstrating that mathematical concepts pose a challenge for students. Beyond individual cognitive difficulties, challenges in mathematics education often stem from decontextualised teaching practices and limited integration of disciplinary knowledge. STEAM+X offers a framework to counteract this fragmentation by fostering transdisciplinary connections and relevance.

Researchers have developed various methods, strategies, approaches, and learning models to overcome this problem. In the last decade, an approach that integrates disciplines such as science, technology, engineering, and mathematics (STEM) [13], [14], [15], [16] has been recommended. Researchers present this approach as a solution to educational challenges, particularly in mathematics education, aiming to equip students with crucial 21st-century skills like creativity, innovation, problem-solving, critical thinking, and collaboration [17], [18], [19], [20]. Over time, several researchers have added art to STEM, making it STEAM, to optimise the creativity of the younger generation [1], [21], [22]. Recently, STEAM evolved into STEAM+X [23], with 'X' being an additional factor in education that influences the development of student competencies. This is because there are quite a lot of factors that influence students' competence in learning mathematics.

Because there are quite a lot of factors that influence students' competence in learning mathematics, studying STEAM+X is quite important. This study aims to investigate how the STEAM+X framework has been applied in mathematics education, with particular attention to the conceptualisation of the "X" component, its disciplinary integration, target educational levels, mathematical content addressed, and the technologies involved. A systematic literature review (SLR) was conducted following the PRISMA protocol to achieve this. There are few studies exploring STEAM+X practices in mathematics education, especially those using systematic literature review (SLR). We expect this study to serve as an additional reference and preliminary investigation into STEAM+X practices in mathematics education. Most previous studies focus on STEM/STEAM practices, not STEAM+X. For example, Pratiwi and Khotimah [24] evaluate the implementation of PjBL-based STEAM in mathematics learning using a hydraulic lift project to learn the concept of measurement in mathematics. Pahmi et al. [25] use a systematic review to assess the influence of STEAM in mathematics education, while Martín-Cudero et al. [26] examine the STEAM approach in mathematics education through a systematic review. The differences between this study and several previous studies can be seen in Table 1.

Table 1. The difference between current research and previous research

Articles	Topics	Research Design
Pratiwi and Khotimah [24]	PjBL-based STEAM	Qualitative descriptive
Pahmi et al. [25]	STEAM	Systematic review
Martín-Cudero et al. [26]	STEAM	Systematic review
Current research	STEAM+X	Qualitative systematic review

Although some previous studies have reviewed the implementation of STEM and STEAM in mathematics education, only a few have systematically analysed the extended STEAM+X approach. For example, one study evaluated STEAM implementation using project-based learning but focused on practical applications rather than providing a comprehensive review [24]. Another systematic review assessed the influence of STEAM in mathematics education on 21st-century skills but did not consider the additional "X" component [25]. A more recent review examined the role of STEAM in secondary mathematics education without addressing transdisciplinary extensions beyond the arts [26]. These works highlight the growing interest in integrated approaches but also reveal a significant gap: the lack of focused reviews on how the additional element "X" shapes mathematics education within the STEAM+X framework. This study addresses this gap by conducting a systematic literature review following the PRISMA protocol, aiming to identify how "X" is conceptualised and applied in mathematics education and to inform future research and practice in this emerging field.

To achieve the previously stated objectives, the researcher formulates several research questions based on this description:

1.1. What does 'X' represent in STEAM+X for mathematics education?
1.2. How is STEAM+X in mathematics education spread across countries?
1.3. How is STEAM+X applied in mathematics education based on research methods?
1.4. How STEAM+X is used in mathematics education varies by publication year.
1.5. How is STEAM+X applied across mathematics content areas?
1.6. How is STEAM+X used at different education levels?
1.7. How is STEAM+X in mathematics education linked to the technology used?

By mapping the existing literature and identifying patterns, gaps, and trends in applying STEAM+X in mathematics education, this review contributes to a better understanding of how interdisciplinary approaches are evolving in the field. The findings are expected to inform both researchers and educators by clarifying how integrating the "X" component can enrich mathematics teaching, promote context-based learning, and effectively leverage technological tools. Furthermore, the study may guide curriculum developers and teacher educators in designing learning experiences that reflect the complexity and richness of transdisciplinary education.

2. METHOD

2.1. Research Design

This study employed the systematic literature review (SLR) method to address several formulated research questions. We chose SLR for its systematic nature, meta-analysis, and in-depth narrative review, which make it highly relevant for comprehensively describing the topic of STEAM+X in mathematics learning [27], [28]. This study focused on observations of journal publications published between 2020 and 2024. We chose this time because we considered articles published in the last five years, published after the COVID-19 pandemic, to represent the latest concepts and provide an overview of the development of STEAM+X.

This study employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline to assess journal publications [29]. We chose PRISMA because it offers a robust framework and comprehensive review of research in specific fields, such as STEAM+X [28]. In addition, PRISMA helped researchers identify problems, gaps, and research trends, understand the main ideas of the literature, accelerate the understanding of ideas in a particular field, and keep up with the rapid pace of scientific publications in recent years [27]. Researchers regarded PRISMA as the best and most accurate approach for discovering STEAM+X practices in mathematics education.

In this study, PRISMA involved several steps: identification, screening, eligibility, and inclusion [30], [31], [32]. The following sections provide a detailed explanation of these steps. Figure 1 provides detailed information on the PRISMA flowchart used in this study. This approach aimed to provide more profound and comprehensive insights into the implementation of STEAM+X in mathematics education, address key questions, and guide future research in this field.

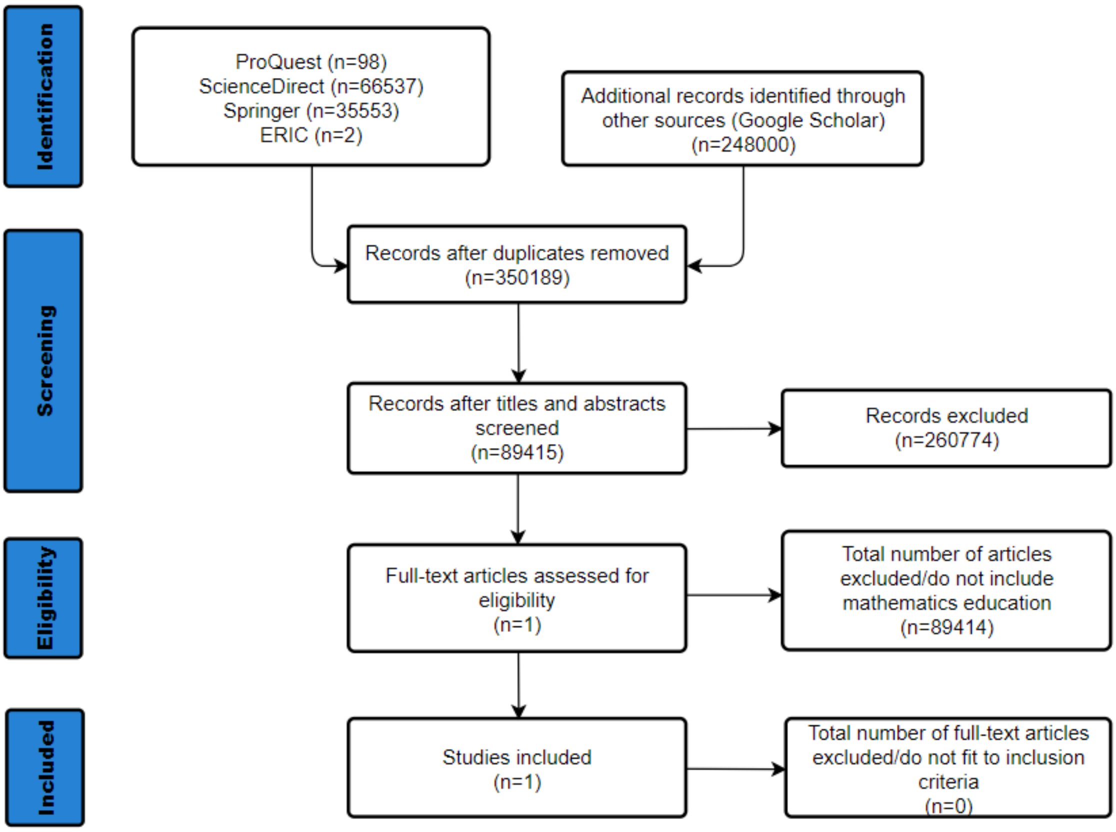

Figure 1. PRISMA results

To ensure transparency and traceability, each step of the review process was supported by specific tools. During the identification stage, searches were conducted using advanced filters on digital databases, and the results were exported to Excel spreadsheets to manage article metadata. The research team manually carried out the screening and eligibility processes using predefined inclusion and exclusion criteria. A shared spreadsheet was used to document decisions, resolve discrepancies, and ensure consistency across reviewers. Reference management software (Zotero) tracks sources and removes duplicates. These tools facilitated the systematic handling of large data sets and ensured the reliability of the review process.

2.2. Systematic Review Process

2.2.1. Identification

Identification was the first step in PRISMA. At this stage, researchers conducted a primary literature search on STEAM+X on several leading sites, such as *ProQuest, ScienceDirect, SpringerLink,* and *ERIC.* An additional search through *Google Scholar.* 'STEAM+X' was used as the keyword due to the absence of other suitable synonyms. Other terms were not used to replace X because the researchers were trying to determine the meaning of X itself. This identification process lasted for one month, from April 15, 2024. The identification results yielded approximately 350,190 relevant articles, with 102,190 from the main sites and 248,000 from additional sites. Figure 1 (presented in Section 2.1) provides detailed information on the PRISMA flowchart used in this study.

2.2.2. Screening

The screening stage involved screening the titles and abstracts of the 350.190 articles identified in the identification step. During this process, articles with the same title were removed, leaving only one for processing. Two articles with the same title were found and were removed. Other inclusion criteria required that articles be published in English between 2020 and 2024. English-language articles were selected to ensure the clarity and accuracy of content interpretation, avoiding the risk of misinterpretation through automated or manual translation. The decision to include articles published between 2020 and 2024 was made to capture the most recent research developments, particularly those emerging after the COVID-19 pandemic, which marked a significant shift in educational practices and technology integration in mathematics education. Systematic reviews, books, book chapters, theses, and conference proceedings were excluded from further analysis. This was because the study only examined articles with direct practice in learning. In addition, books, book chapters, theses, and conferences underwent a review process that was less strict and detailed than Scopus/WoS journals. The screening results revealed that 260,774 articles failed to meet the inclusion criteria, and identifying one duplicate article left 89,415 articles for further analysis.

The screening process used Excel spreadsheets where all titles and abstracts were listed. A filtering system was applied to verify language, publication date, and document type. Articles that did not meet the basic criteria were marked and excluded. No automated text analysis software was used; the researchers carried out the process manually to ensure interpretive precision.

The high number of initial results (350,190) was due to the broad search syntax and multiple general-purpose academic databases, which often return duplicate and loosely related documents. Automated filters were applied at the database level to limit the results to articles published between 2020 and 2024 in English and within the education or STEM domains. A manual screening process was conducted after removing duplicates and irrelevant entries based on title and abstract. Two researchers independently carried out the screening and eligibility stages to ensure rigour and minimise selection bias. Any disagreements were resolved through discussion and consensus. A predefined set of inclusion and exclusion criteria was used consistently across all stages, and a shared spreadsheet was used to document decisions and maintain transparency. This process helped reduce subjectivity and increase the reliability of the final selection.

2.2.3. Eligibility

In the eligibility stage, the inclusion criteria were that articles must contain STEAM+X practices in mathematics education. The researcher did not use a combination of STEAM with other aspects because they did not yet clearly understand the meaning of X itself. In fact, through this research, the researcher wanted to discover the meaning of X. The researcher conducted two analyses: the first involved scrutinising each article's title and abstract. Articles lacking STEAM+X in the title or abstract did not proceed to the following analysis. Second, articles with STEAM+X in the title and abstract were further analysed, scrutinising the research objectives, methodology, results, and discussion to confirm the inclusion of STEAM+X practices in mathematics education. Articles that did not meet these criteria were rejected. The analysis showed that only one article was eligible for the next stage.

Articles were deemed eligible if they met the following criteria: (1) explicit mention of STEAM+X in the title or abstract; (2) discussion of practices related to mathematics education; (3) clear articulation of the "X" component within the STEAM+X framework; (4) inclusion of methodological information regarding the implementation of STEAM+X; and (5) publication in peer-reviewed journals indexed in Scopus. Articles that lacked evidence of practical application or theoretical grounding in mathematics education were excluded.

2.2.4. Inclusion

At this stage, the inclusion criteria based on the research questions were that the article must contain an explanation of the meaning of 'X' in STEAM+X, a clear research methodology, elements of mathematical content, a description of the target educational level of STEAM+X practices, and a description of the technology used in STEAM+X. Apart from that, the inclusion criteria used were that articles had to be indexed by Scopus. The analysis of the remaining articles revealed that only one article, Bedewy and Lavicza's [23], met all the inclusion criteria. The article was then used as the basis for answering all research questions. Thus, this PRISMA process helped filter and select the most relevant and high-quality articles to comprehensively answer research questions related to STEAM+X practices in mathematics education.

3. RESULTS AND DISCUSSION

3.1. What Does 'X' Represent in STEAM+X for Mathematics Education?

In the reviewed study [23], the concept of "X" in STEAM+X was interpreted as encompassing three main domains: architecture, history, and culture, each playing a distinct role in enriching mathematics education. The analysis highlights the importance and multifaceted meaning of 'X' in the STEAM+X approach. First and foremost, 'X' is associated with architecture, and all teacher participants used architectural models in STEAM practices. This was because architecture helped to explain 3D geometry effectively.

Integrating architecture with history and culture made learning more intriguing and contextual. For example, Leopold [33] stated that architectural design was based on geometric structures originating from the transformation of ideas, while Ajmera [34] emphasised the important role of geometry in architecture during the Renaissance era. Previous studies such as Giurea et al. [35], [36], which emphasised the fundamental role of geometric knowledge in learning architecture, supported Carroll and Rykken's [37] integration of architectural design into geometry learning.

Second, 'X' could mean culture. Most teacher participants [23] adopted a cultural perspective when selecting architecture for STEAM practices, tailoring it to each country's unique culture. This supported Stigler and Baranes [38] view that cultural representation influenced the development of one's mathematical knowledge and was also an integral part of it. White et al. [39] emphasised the importance of cultural discussions in mathematics learning, which was also in line with the concept of ethnomathematics that explored the relationship between mathematics and culture [30], [40], [41]. Previous studies [42], [43], [44] have also demonstrated that culture can facilitate the learning of various mathematical concepts.

Third, 'X' refers to history. Teachers could introduce history through the choice of architecture used in STEAM practices. Teachers collected historical data from the chosen architecture, collaborating with history teachers to develop learning syllabuses. This showed the transdisciplinary connections that occurred between various disciplines. Transdisciplinary approaches created an intellectual framework that transcended disciplinary boundaries [45] and connected science with society, including stakeholders in education [46]. Despite its infrequent study in education, this concept became crucial in the 21st century to ensure the sustainability of educational innovation [47].

3.2. How Is STEAM+X in Mathematics Education Spread Across Countries?

Despite focusing on a single study [23], the research involved participants from multiple countries, allowing for a cross-national perspective on implementing STEAM+X in mathematics education. In other words, these countries had implemented STEAM+X practices in mathematics education. Figure 2 shows the distribution of research across several countries. Based on Figure 2, only eight countries practised STEAM+X in mathematics education: Austria, Indonesia, Egypt, Tunisia, Palestine, Singapore, Libya, and Saudi Arabia.

Only eight countries have implemented STEAM+X practices [23], with Singapore being the only country in the top fifteen PISA mathematics scores to do so. Spain, Italy, China, the UK, Germany, Russia, the US, the Netherlands, Norway, and Sweden, on the other hand, implemented STEAM practices more widely [21]. Asian, American, and European countries had researched the most on STEAM practices in mathematics education [22], [25], indicating that STEAM+X practices were still new and required more research from various countries.

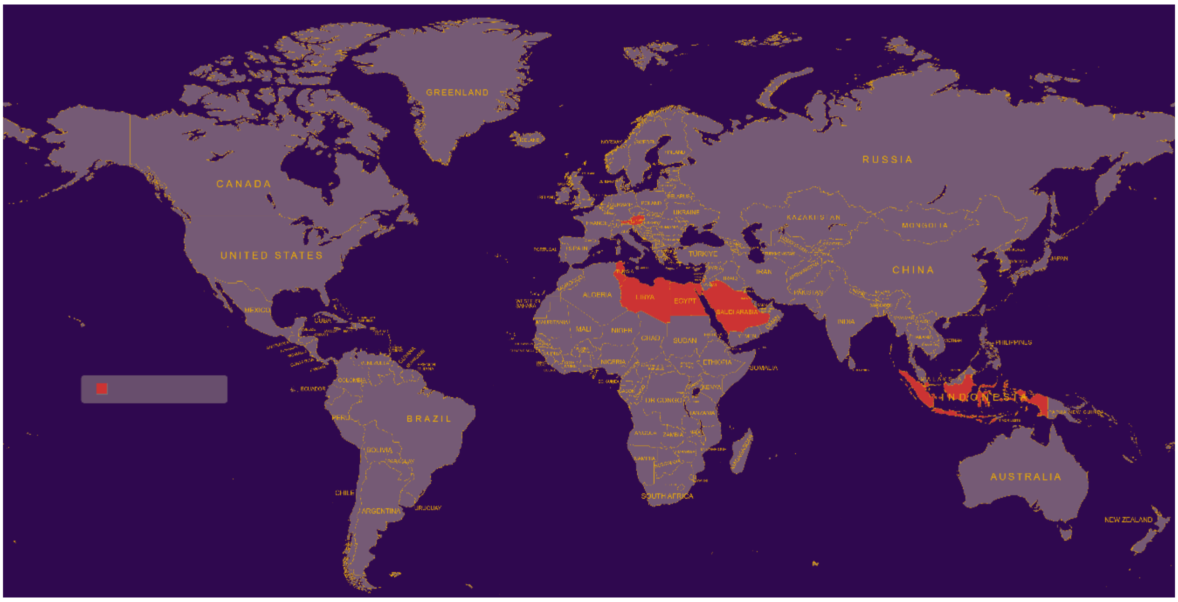

Figure 2. STEAM+X practices in mathematics education by country (*Note*: Data derived from a single study [23] involving participants from these countries)

3.3. How Is STEAM+X Applied in Mathematics Education Based on Research Methods?

The selected study employed a design-based research (DBR) methodology, integrating qualitative and quantitative approaches to investigate the implementation of STEAM+X in authentic educational settings [23]. This methodological choice reflects interdisciplinary educational innovations’ complex, context-sensitive nature, particularly those involving mathematics and cultural or artistic components. Design-based research is especially suitable for studying interventions that evolve through iterative implementation cycles, reflection, and redesign [48], [49].

In this case, using a DBR approach allowed the authors to collaboratively develop and refine instructional tasks and assess their feasibility in real classrooms, aligning with the core principles of STEAM+X. The mixed-methods design supported the triangulation of data from classroom observations, interviews, and learning products, contributing to the validity of the findings.

While conclusions must be drawn with caution due to the reliance on a single study, the methodological rigour and the use of DBR point to a valuable strategy for future research in this domain. In particular, DBR offers a promising avenue for exploring how transdisciplinary tasks can be co-designed with teachers, iteratively tested, and theorised in ways that bridge didactic theory and classroom practice—an imperative also highlighted in the broader field of mathematics education.

3.4. How Does STEAM+X Use in Mathematics Education Vary by Publication Year?

An analysis of a previous article by Bedewy and Lavicza [23] revealed that the practice of STEAM+X in mathematics education first appeared in 2023. Hal ini kemungkinan disebabkan karena kriteria inklusi yang ketat dalam penelitian ini, salah satunya adalah artikel terindeks Scopus/WoS. In other words, there was a lack of widespread research publications focusing on STEAM+X. The first published research on STEAM+X practices in mathematics education was only in 2023, with only a few available references [22], [26]. Therefore, we recommended making this research the primary focus for the upcoming years.

3.5. How Is STEAM+X Applied Across Mathematics Content Areas?

The available evidence shows that STEAM+X practices in mathematics education have concentrated almost entirely on geometry, particularly 2D and 3D geometric concepts [23]. There is a noticeable absence of implementations involving key mathematical domains such as number theory, algebra, measurement, data analysis, probability, or calculus. This narrow content focus aligns with prior findings in STEAM literature [24], [50], where geometry is often favoured due to its strong visual and spatial components, which facilitate interdisciplinary integration. However, the lack of diversity in mathematical content reveals an important research gap. Future studies are encouraged to explore how the STEAM+X framework can be extended to support the teaching and learning of other mathematical areas, thereby broadening its educational potential.

3.6. How Is STEAM+X Used at Different Education Levels?

Current evidence indicates that STEAM+X practices in mathematics education have been implemented almost exclusively at the senior high school level and in programs involving preservice and in-service mathematics teachers [23]. There are no documented elementary or junior high school applications within the reviewed literature. This contrasts sharply with the broader STEAM literature, where implementations span all educational levels, including early childhood and primary education [24], [25], [50].

This concentration at the upper-secondary and teacher-training levels may be due to the greater curricular flexibility, availability of technological resources, or the interdisciplinary competencies required to enact STEAM+X models effectively. However, the lack of early-stage implementations represents a missed opportunity to introduce transdisciplinary thinking from a younger age. Future research could explore how to adapt the STEAM+X framework to younger learners' developmental stages and how teacher preparation programs might support this expansion.

In the context of our review, the values "1" and "0" previously shown in the visual representation indicated whether STEAM+X practices had been implemented at a given educational level. The "1" signified that the level appeared in the reviewed article, while "0" indicated no documented implementation. Specifically, STEAM+X practices were reported at the senior high school level (SHS) and among preservice (PMT) and in-service teachers (IST) but not at the elementary (ES) or junior high school (JHS) levels. This absence may reflect a lack of research and practical challenges in adapting transdisciplinary models to younger learners' contexts.

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3.7. How Is STEAM+X in Mathematics Education Linked to the Technology Used?

The reviewed study [23] reported the integration of diverse technologies in STEAM+X practices, encompassing both digital tools—such as GeoGebra, augmented and virtual reality applications, and Microsoft Teams—and physical materials like origami, cardboard models, 3D printing, and injection-moulded toys. This combination illustrates the adaptability of the STEAM+X approach to different technological contexts and suggests its potential to enhance mathematics learning through multimodal resources. However, this potential may be limited if technologies are integrated merely instrumentally, without rethinking the epistemological and didactic frameworks that support their use. This concern has been raised in mathematics education research, where studies warn against superficial applications that do not transform classroom practices [52], [53].

However, practical implementation reveals persistent challenges, particularly in how teachers formulate tasks. Technology integration is often limited to applying routine mathematical procedures within artificial contexts, resulting in deterministic problems with single answers. This restricts the transdisciplinary and exploratory potential that STEAM+X is intended to foster. Consequently, we have observed the need for professional development initiatives aimed at helping teachers design more authentic tasks, integrate technology meaningfully, and manage the classroom environment in ways that align with the pedagogical goals of STEAM+X. This view aligns with perspectives in mathematics education that emphasise the importance of culturally responsive and context-based learning environments. Some theoretical approaches, such as the Ontosemiotic Approach [54] and Ethnomathematics [55], suggest that mathematical knowledge is not value-neutral but culturally and historically situated, shaped by the practices and meanings of diverse communities.

To better understand the complexity of these challenges, it is essential to situate STEAM+X within the wider ecosystem of mathematics education. Figure 3 presents a conceptual map that highlights a variety of theoretical perspectives and interdisciplinary models that currently inform the field.

This interpretative diagram, adapted by the authors, positions STEAM+X alongside major lines such as ethnomathematics, the ontosemiotic approach, the French didactics school, and critical mathematics education. The dotted links emphasise that the map is not exhaustive but rather indicative of the richness and plurality of the discipline. Within this constellation, STEAM+X stands out as one promising pathway to address the evolving demands of interdisciplinary, socially relevant, and technologically enriched mathematics education.

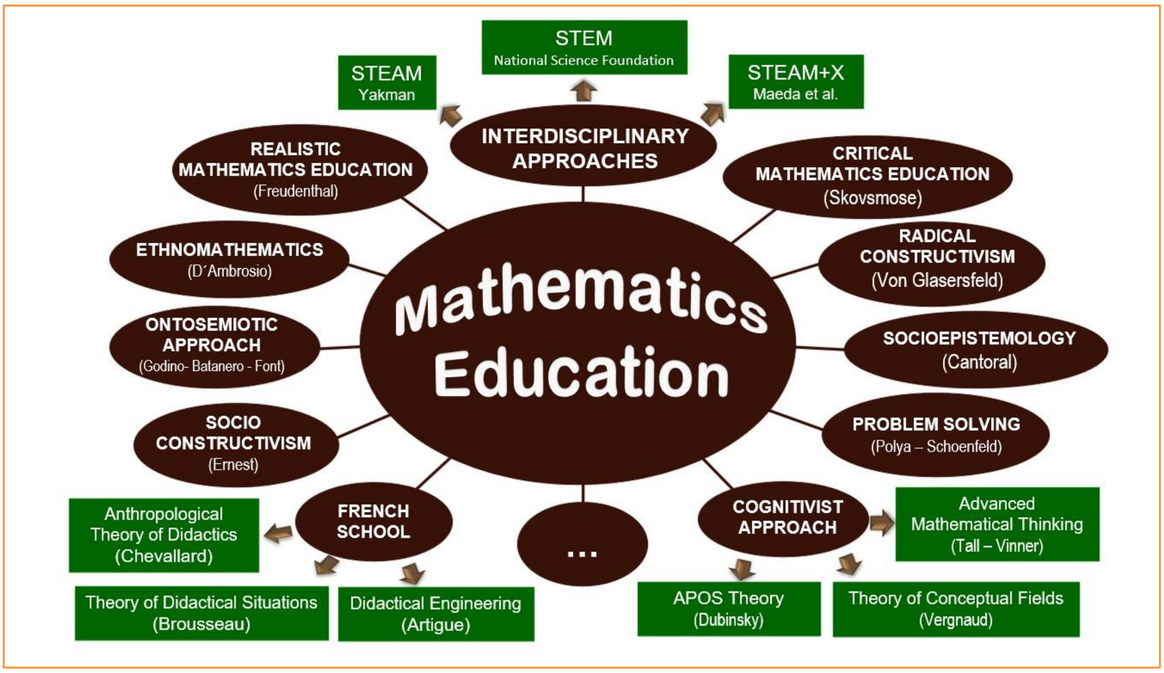

Figure 3. Conceptual map of major approaches in mathematics education and the positioning of STEAM+X (adapted by the authors)

It is important to acknowledge that this review is based on a single article that met the strict inclusion criteria, limiting the findings' generalizability. While the analysis provides valuable insights into how STEAM+X has been implemented in mathematics education, the results must be interpreted with caution. To enrich the discussion, comparisons have been made with broader STEAM literature that reveals a wider range of content areas, educational levels, and technological applications. This contrast underscores the specificity—and the limitations—of the current evidence on STEAM+X.

Future systematic reviews could address this limitation by expanding search strategies to include additional languages, gray literature, and alternative indexing databases. Broadening the temporal range or refining search terms may also increase the retrieval of relevant studies, thus enabling more comprehensive analyses. Despite its narrow scope, the present study is a foundational step toward mapping this emerging research field.

4. CONCLUSION

The analysis leads to several relevant conclusions. First, the "X" in STEAM+X practices in mathematics education refers primarily to architecture, history, and culture. Second, only a few countries—such as Singapore, Indonesia, Austria, and those in the MENA region (Egypt, Libya, Saudi Arabia, Palestine, and Tunisia)—have implemented STEAM+X practices between 2020 and 2024. Third, the selected study employed a mixed-methods design rooted in design-based research. Fourth, the only identified publication meeting the inclusion criteria appeared in 2023, underscoring this research field's novelty and underrepresentation. Fifth, existing implementations focused almost exclusively on geometry-related content. Sixth, applications were observed predominantly at the senior high school level and in mathematics teacher education, both preservice and in-service.

Finally, a range of digital and physical technologies were used, including GeoGebra, augmented and virtual reality, 3D printing, and origami.

Based on these findings, several directions for future research can be proposed. First, further exploration is needed into the multiple interpretations and educational implications of the “X” component, particularly in relation to social, cultural, and disciplinary diversity. Second, expanding the scope of STEAM+X research to include additional countries, educational levels, and timeframes would contribute to a more comprehensive understanding of its potential. Third, methodological diversification—using both qualitative and quantitative approaches—could enhance the depth and validity of future findings. Fourth, researchers should explore how STEAM+X can be applied to a wider mathematical content beyond geometry, especially in elementary and junior high school contexts. Fifth, attention should be given to how digital and physical technologies are meaningfully integrated into tasks rather than being used as superficial add-ons.

In particular, integrating cultural, historical, and architectural dimensions into mathematics education opens new possibilities for contextualising abstract concepts and promoting interdisciplinary understanding. Educators could, for example, design tasks that analyse geometric structures in historical architecture, explore mathematical concepts embedded in local cultural artefacts or examine how measurement practices vary across civilisations. To facilitate such innovations, curriculum frameworks should explicitly encourage connections between mathematics and the humanities, and teacher training programs should include modules on the design of transdisciplinary and culturally responsive learning experiences. These results confirm the narrow but emerging presence of STEAM+X in mathematics education and emphasise the urgency of further research that diversifies contexts, content, and methodologies while deepening this promising approach’s theoretical and practical foundations.

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