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*Review*

# STEM/STEAM, ethnomathematics, and TPACK: A systematic literature review and implications for project-based Ethno-STEAM in pre-service mathematics teacher education

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**Abstract:** Innovative learning plays a crucial role in preparing students to tackle global challenges in the 21st century. In the context of this study, innovative learning is understood as instructional approaches that integrate STEM/STEAM education, ethnomathematics or cultural contexts, and project-based learning to support the development of technological pedagogical content knowledge (TPACK) in pre-service mathematics teacher education. Despite the growing attention to innovative pedagogical approaches, research examining the intersection of STEM/STEAM education, ethnomathematics, and TPACK in pre-service teacher education remains fragmented. Therefore, this

study conducted a literature review to examine how STEM/STEAM, ethnomathematics (ethno), project-based learning (PjBL), and TPACK are represented and connected in the literature of pre-service mathematics teachers' education. A systematic literature review (SLR) of 17 Scopus-indexed articles from the past seven years was conducted. The analysis employed descriptive statistics, network analysis, and qualitative synthesis to identify research trends, dominant themes, and emerging patterns. The analysis suggests that PjBL–ethno–STEAM emerges as a promising conceptual direction for supporting TPACK development, although empirical evidence remains limited. The study also discusses challenges, opportunities, implications, and recommendations for future research and applications in educational settings. These findings aim to inform the development of innovative and contextually relevant mathematics teachers' education curricula.

**Keywords:** PjBL; pre-service mathematics teacher; ethno-STEAM; TPACK; systematic literature review (SLR)

## 1. Introduction

In the 21st century education landscape, embracing innovative learning approaches is paramount due to the rapid evolution of technology and social dynamics. Groff [1] emphasized that technology is a crucial element for driving change in education. Educators are encouraged to explore and implement effective strategies that not only deliver content but also cultivate critical skills such as creative thinking, collaboration, and adaptability. Context-specific innovations are more likely to be adopted swiftly, preventing delays in implementing new learning methods [2]. Therefore, enhancing practices such as project-based learning (PjBL), technology integration, and solution-oriented education is essential for creating responsive and relevant educational experiences that meet the demands of the modern era.

Innovative learning in education bridges the gap between theory and practice, preparing students for real-world challenges. This approach is essential for responsive education, equipping students to tackle complex global issues [3,4]. Project-based learning (PjBL) offers a hands-on learning alternative where students explore real-life projects relevant to their daily lives [5,6]. Integrating PjBL with the ethno–STEAM approach, which combines science, technology, engineering, arts, and math with local wisdom and culture, enhances learning by providing a rich and meaningful experience. PjBL has been shown to boost student engagement and critical thinking skills, and when combined with cultural elements through ethno-STEAM, the impact is even more significant [7].

From a teacher education perspective, the integration of interdisciplinary approaches presents both opportunities and challenges, particularly in relation to the development of technological pedagogical content knowledge (TPACK). TPACK represents the interconnected knowledge required for effective teaching in digital learning environments, encompassing content knowledge, pedagogical strategies, and the purposeful use of technology [8,9]. Pre-service teachers often face difficulties in integrating these components coherently, especially when designing innovative and interdisciplinary learning experiences [10–13]. As a result, strengthening TPACK has become a central focus in teacher education programs, with professional development initiatives emphasizing the importance of cross-disciplinary integration and contextualized instructional design [3,14].

Despite the growing body of research addressing STEM/STEAM education, cultural integration,

and TPACK in their education, there remains a lack of systematic synthesis that examines how these components are positioned and interconnected across the literature, particularly in the context of pre-service mathematics teacher education. Previous studies tend to focus on individual dimensions such as technology integration, project-based pedagogy, or cultural relevance without offering a comprehensive overview of emerging patterns, overlaps, and research gaps. Consequently, there is a need for a systematic literature review that maps research trends, identifies dominant and peripheral themes, and explores how project-based and culturally grounded approaches may inform the future development of integrated ethno–STEAM-oriented practices for enhancing TPACK.

Therefore, this study aims to systematically review the literature on STEM/STEAM, ethnomathematics or cultural contexts, and TPACK in pre-service mathematics teacher education. Rather than assuming the existence of a fully established PjBL-ethno-STEAM model, this review examines how these elements are represented and combined across studies published between 2018 and 2024. By synthesizing existing evidence, the study seeks to identify research trends, highlight gaps, and propose implications for the development of project-based ethno–STEAM as an emerging direction for supporting TPACK in pre-service mathematics teachers' education.

### 1.1. Project-based learning (PjBL)

Project-based learning (PjBL) is a learner-centered instructional approach in which students engage in extended projects to address authentic, real-world problems [15,16]. Through inquiry-driven activities, PjBL emphasizes collaboration, critical thinking, and problem-solving, making learning more meaningful and contextually relevant. The PjBL approach begins with an essential question, followed by planning a project, creating a schedule, monitoring progress, assessing outcomes, and reflecting on the learning experience [15].

In mathematics education, PjBL has been reported to support students' conceptual understanding by connecting mathematical ideas to real life application [16,17]. Research shows that PjBL improves academic performance [16] and boosts motivation by making math more engaging and practical [17]. Moreover, PjBL fosters critical thinking, problem-solving [18], collaboration, and communication skills, all of which are crucial for academic success and future career prospects [15,16].

### 1.2. Ethnomathematics, science, technology, engineering, arts, and mathematics (ethno–STEAM)

Ethnomathematics emphasizes that mathematical knowledge is not solely a universal and abstract construct, but is also shaped by cultural practices, social contexts, and local ways of knowing [19,20]. Mathematics is embedded in cultural activities and meaningfully connected to students' life experiences including through culturally relevant and technology-supported learning environment [21]. D'Ambrosio conceptualized ethnomathematics as originating from human efforts to solve everyday problems and construct knowledge systems within a specific cultural setting. Building on this view, the integration of science, technology, engineering, arts, and mathematics (STEAM) has been proposed to foster interdisciplinary learning that balances technical competence with creativity and contextual relevance [22–25]. Ethno-STEAM has emerged as an approach that combines STEAM principles with local cultural values, practices, and artefacts, thereby situating

interdisciplinary learning within meaningful cultural contexts and reinforcing students' sense of identity [23,24]. Within STEM/STEAM and ethno–STEAM approaches, project-based learning is frequently discussed as a pedagogical strategy because it provides a structured way to enact interdisciplinary and culturally grounded learning through authentic projects and collaborative inquiry.

### 1.3. Technological pedagogical content knowledge (TPACK)

The rapid advancement of digital technology has increased the need for teachers to effectively integrate technology into the teaching and learning process. The TPACK framework, developed by Mishra and Koehler based on Shulman's concept of pedagogical content knowledge (PCK), conceptualizes teachers' knowledge as an interaction among content knowledge, pedagogical knowledge, and technological knowledge [8,25]. TPACK highlights that effective technology integration requires not only technical proficiency but also pedagogically sound and content-specific applications.

Research suggests that TPACK development is influenced by instructional models and learning experiences provided in teacher education programs [26,27]. Studies have shown that pedagogical and content knowledge play an important role in shaping teachers' TPACK, particularly when technology is meaningfully embedded within instructional practices. Consequently, interdisciplinary and technology-integrated learning approaches, such as culturally grounded STEAM-based designs, have been discussed as potential avenues for supporting the development of pre-service teachers' TPACK. In this review, a distinction is made between technology as a component of STEAM learning (e.g., digital tools used within interdisciplinary instruction) and technology as professional knowledge that pre-service teachers must develop to design, implement, and reflect on STEAM-based pedagogical practices. This distinction is captured through the TPACK framework.

### 1.4. Conceptual framework: Toward PjBL–ethno–STEAM for TPACK development

Based on the review literature, it is evident that ethnomathematics, STEM/STEAM, PjBL, and TPACK have largely been examined as related but often separate strands of research in pre-service mathematics teachers' education. While each of these domains has demonstrated potential contributions to meaningful learning and teacher competence development, their integration remains fragmented and uneven across existing studies. Drawing on these strands, this study proposes a conceptual framework of PjBL–ethno–STEAM (Figure 1) as an emerging pedagogical configuration rather than a fully established instructional model. In this framework, STEM/STEAM integration serves as the disciplinary foundation, which is enacted through PjBL and grounded in ethnomathematical contexts. These conditions collectively create opportunities for collaborative inquiry and authentic learning experiences that may support the development of pre-service teachers' TPACK.

Importantly, the framework does not assume that all reviewed studies implement these elements simultaneously. Instead, it functions as an analytical lens to synthesize patterns, identify gaps, and explore future possibilities for integrating PjBL–ethno–STEAM in pre-service mathematics teachers' education.

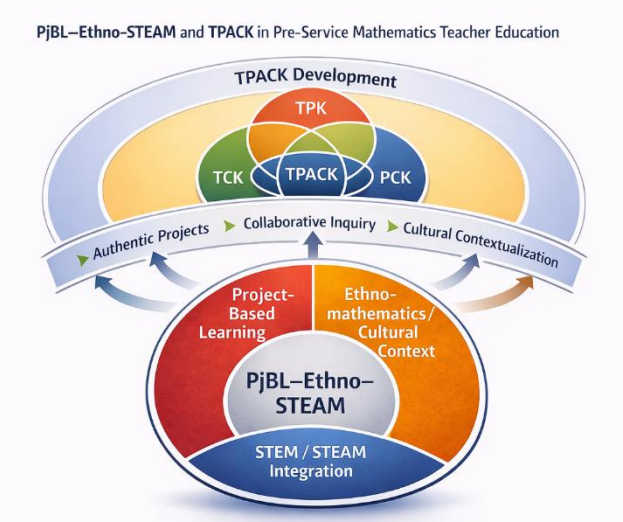


**Figure 1.** Conceptual framework of PjBL–ethno-STEAM and its potential relationship with TPACK development in pre-service mathematics teachers' education.

The framework synthesizes insights from ethnomathematics, STEM/STEAM integration, and project-based learning to illustrate potential pathways for supporting TPACK development. It reflects an emerging conceptual opportunity identified through the systematic literature review rather than a prescriptive instructional model.

### 1.5. Research aims and questions

There is an extensive number of publications on the relationship between STEAM and TPACK, particularly in the fields of technology and education [26]. However, there is a lack of in-depth discussion on PjBL–ethno–STEAM specifically. Therefore, this study aims to explore the implementation of PjBL–ethno–STEAM on enhancing the TPACK skills of pre-service teachers. The study addresses the following questions:

(1) What are the research trends in the literature on STEM/STEAM, ethnomathematics or cultural contexts, and TPACK in pre-service mathematics teachers' education from 2018 to 2024?
(2) How are project-based learning, ethno–STEAM perspectives, and TPACK conceptualized and positioned across existing studies on pre-service mathematics teachers?
(3) What gaps, challenges, and future research opportunities are identified in relation to the integration of STEM/STEAM, ethnomathematics, PjBL, and TPACK, and what implications do these findings suggest for the development of PjBL–ethno–STEAM in pre-service mathematics teachers' education?

## 2. Methods

This study employed a systematic literature review (SLR) approach, which involved reviewing relevant studies through systematic methods to address a specific research question [28]. This study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) model, which included identification, screening, eligibility, and inclusion [29,30].

### 2.1. Identification phase

The study started with formulating the problem to be addressed in the review. This stage included identifying needs, determining the scope of the research, formulating research questions, and identifying stakeholders or research partners [31–33]. The next stage involved developing and validating the review protocol. This stage aims to create a guide or protocol that will be used throughout the SLR process to ensure that the SLR is conducted consistently and transparently. Key tasks at this stage include selecting keywords, choosing databases, and establishing the inclusion and exclusion criteria [34,35].

The selection of keywords was carefully designed to capture studies related to STEM/STEAM education, ethnomathematics, PjBL, and TPACK. Although the terms "teacher education" and "pre-service teachers" were not consistently included in the search strings, the focus on teacher education was ensured through the application of inclusion and exclusion criteria and subsequent screening procedures. Only studies situated within teacher education contexts, particularly those involving pre-service mathematics teachers, were retained for further analysis. In terms of database selection, Scopus was the primary database due to its comprehensive coverage of peer-reviewed journals in education, social science, and STEM-related fields. Google Scholar was used as a supplementary database to minimize the risk of publication bias and to capture relevant studies addressing ethnomathematics and local cultural contexts, which may be underrepresented in indexed databases. Although Google Scholar does not provide full transparency regarding its indexing process, its use in this review was limited to a complementary role, and all retrieved articles were subjected to some rigorous inclusion and exclusion criteria to ensure the transparency and reproducibility of the SLR process.

The review focused on studies published between 2018 and 2024 to capture recent research in STEM/STEAM education, ethnomathematics, PjBL, and TPACK within teacher education. Ethnomathematics was included as a distinct search term to capture culturally grounded studies that may not explicitly adopt STEM/STEAM or ethno-STEAM terminology but are theoretically relevant to culturally contextualized STEAM learning in mathematics education. This period reflects the growing emphasis on STEAM education and the maturation of the TPACK framework in teacher education, as well as the acceleration of digital integration and pedagogical innovation in recent years. Therefore, this time frame was selected to emphasize contemporary development rather than historical trends. Finally, the researchers defined the inclusion and exclusion criteria to ensure that the identified literature was relevant to the review [32,34].

### 2.2. Screening phase

The screening phase comprises multiple stages. The first stage involves searching for literature using electronic databases or a backward and forward search system [32]. The literature search was conducted using predefined Boolean search strings derived from the research questions. The primary database used in this study was Scopus metadata, followed by Google Scholar metadata as the secondary database. The researchers categorized research questions into concept domains to help them derive keywords to use in the search process [31]. The keywords used in the literature search process are listed in Table 1. After compiling a list of references, the researchers filtered each article to determine its inclusion for data extraction and analysis [32].

**Table 1.** Literature search keywords.

| Database | Search keywords |
|---|---|
| Scopus | TITLE-ABS-KEY (“ethnomathematics” AND “project based learning”) OR TITLE-ABS-KEY (“ethnomathematics” AND “steam”) OR TITLE-ABS-KEY (“steam” OR “stem” AND “tpack” OR “tpck”)) |
| Google Scholar | “project based learning” AND “ethnomathematics” AND “steam” |

### 2.3. Eligibility phase

In the eligibility phase, full-text articles were assessed in detail based on the predefined inclusion and exclusion criteria. Articles were included if they (a) focused on STEM/STEAM education, ethnomathematics, project-based learning, and/or TPACK, (b) involved pre-service mathematics teachers or teacher education contexts, and (c) provided empirical, review-based, or analytical insights relevant to the research questions. Studies were excluded if they did not align with the scope of the review, lacked relevance to teacher education, or did not provide sufficient information related to the analytical dimensions of the study. The final selection of eligible articles followed the PRISMA guidelines, ensuring a transparent and systematic selection process.

The initial screening involved using titles, keywords, and relevant databases, yielding 179 documents from Scopus (n = 123) and Google Scholar (n = 56). The researchers then analyzed the titles and abstracts based on the exclusion and inclusion criteria [31]. Any research not relevant to the research question was excluded. The inclusion and exclusion criteria are outlined in Table 2.

**Table 2.** Selection criteria.

| Criteria | Inclusion | Exclusion |
|---|---|---|
| Language | English | Other than English |
| Publication year | 2018–2024 | Before 2018 |
| Publication type | Journal articles and proceedings | Other than journal articles and proceedings |
| Access | Open access | Closed access |
| Subject area | Social science, computer science, engineering, psychology, mathematics, multidisciplinary, arts, and humanities | Other than social science, computer science, engineering, psychology, mathematics, multidisciplinary, arts, and humanities |

A total of 88 documents passed to the screening stage; 41 documents met the requirements, while 47 did not. Among the 41 eligible documents, 17 were identified as potentially addressing the research questions. Of these 17 studies, 15 were sourced from Scopus, and 2 from Google Scholar. The selection process is illustrated in Figure 2.

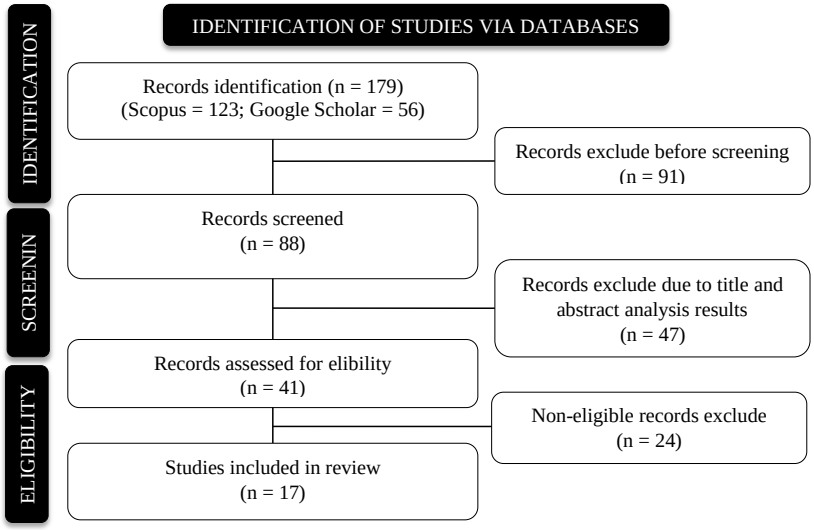


**Figure 2.** PRISMA model flowchart.

### 2.4. Inclusion phase and data analysis

Following the eligibility assessment, the final set of included studies was subjected to a systematic data analysis. The selected documents were initially coded based on descriptive information, including author, year of publication, publication source, paper title, publication type, geographical context, main findings, and suggestions for further research. The researchers used MS Excel to organize and manage the extracted data.

During data analysis, included studies were examined based on the presence and emphasis of four analytical dimensions: (1) project-based learning (PjBL), (2) ethnomathematics, (3) STEM/STEAM, and (4) TPACK components. These dimensions were employed as analytical coding categories to capture varying configurations and degrees of integration across the reviewed studies, rather than assuming their simultaneous implementation in all cases. Each study was coded based on the information reported in the research objectives, instructional design, learning activities, and assessment focus, enabling a systematic comparison of how these elements were positioned and combined within the literature.

To support quantitative analysis, RStudio and VOSViewer were used to examine publication trends, keyword co-occurrence, and network relationships among research themes. In addition, qualitative analysis was conducted to identify dominant patterns, research gaps, and emerging directions related to the integration of STEM/STEAM, cultural contexts, PjBL, and TPACK in pre-service mathematics teachers' education. The results of the literature analysis are reported through quantitative descriptive analysis, network analysis, qualitative literature analysis, and critical review analysis.

## 3. Results

The researchers' analysis focused on three aspects: research profile and network analysis, content analysis, and an analysis of the studies' limitations, implications, and suggestions for future research. The analysis revealed an increase in the number of studies on ethnomathematics, project-based learning, and STEM/STEAM from 2019 to 2022. All selected studies were conducted within the last

decade (Figure 3). Additionally, Figures 4 and 5 illustrate the trends in relevant affiliations and keyword associations with authors.

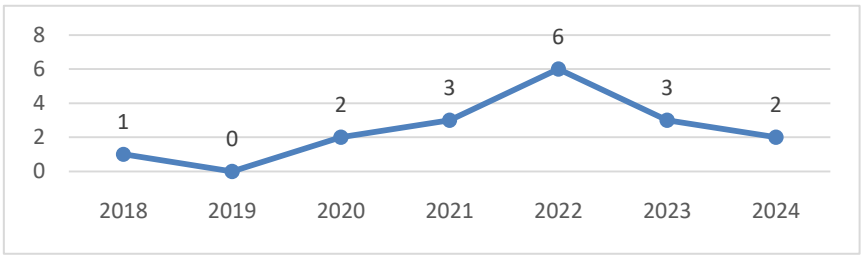


**Figure 3.** Publication quantity from 2018 to 2024.

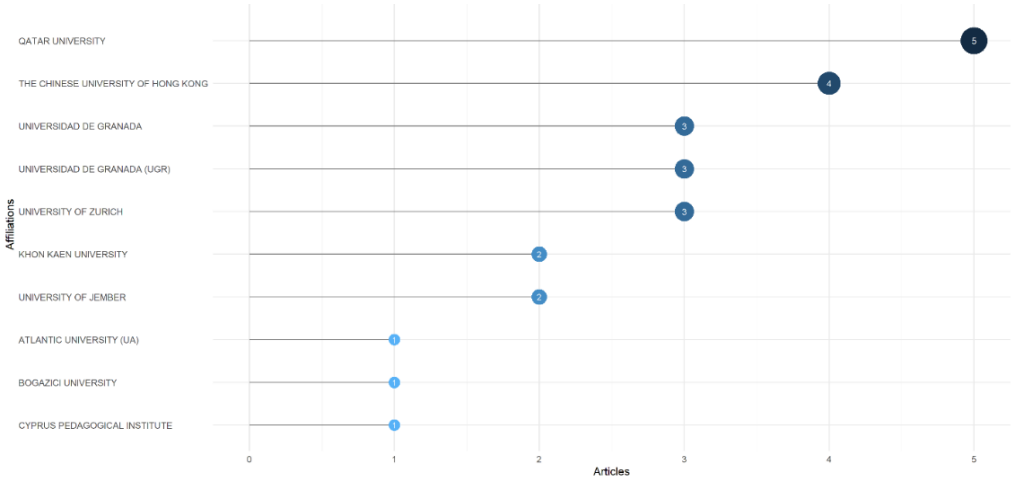


**Figure 4.** Most relevant affiliations.

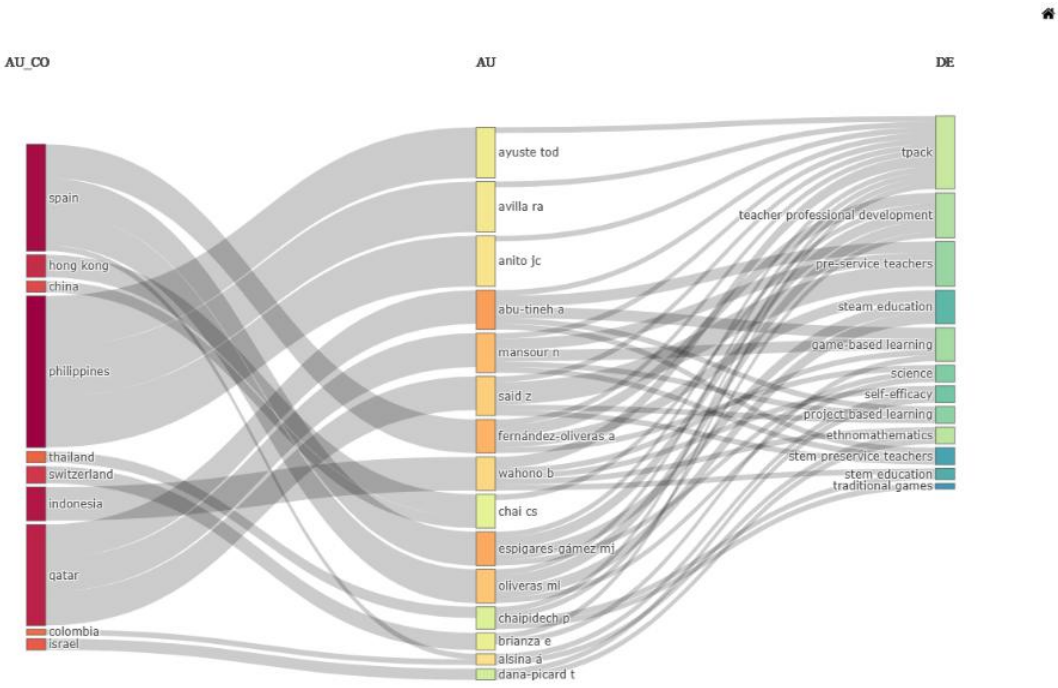


**Figure 5.** Three-field plot.

Figure 2 shows a decline in research quantity from 2022 to 2024. Meanwhile, Figure 3 demonstrates the international collaborations made among authors, such as a collaboration between a Colombian author and a Spanish author on research related to the network between ethnomathematics and STEAM education. Moreover, Figure 3 highlights that the 17 articles are affiliated with 10 different universities.

Figure 4 displays a three-field plot connecting the country of origin, author, and keywords of the articles. The three-field plot shows that the 17 studies are distributed across 10 countries: Spain (4), Philippines (3), Qatar (3), Hong Kong (1), China (1), Thailand (1), Switzerland (1), Indonesia (1), Colombia (1), and Israel (1). This study employed two keyword-based data visualizations: the three-field plot and co-occurrence analysis. The third column in Figure 4 also shows the keywords in relation to authors [36]. The subsequent analysis involves keyword network analysis using VOS Viewer, as shown in Figures 6 and 7.

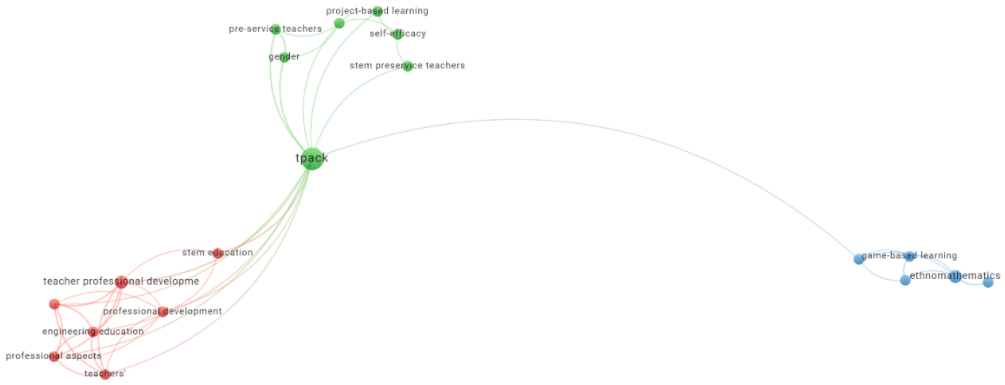


**Figure 6**. Keyword map.

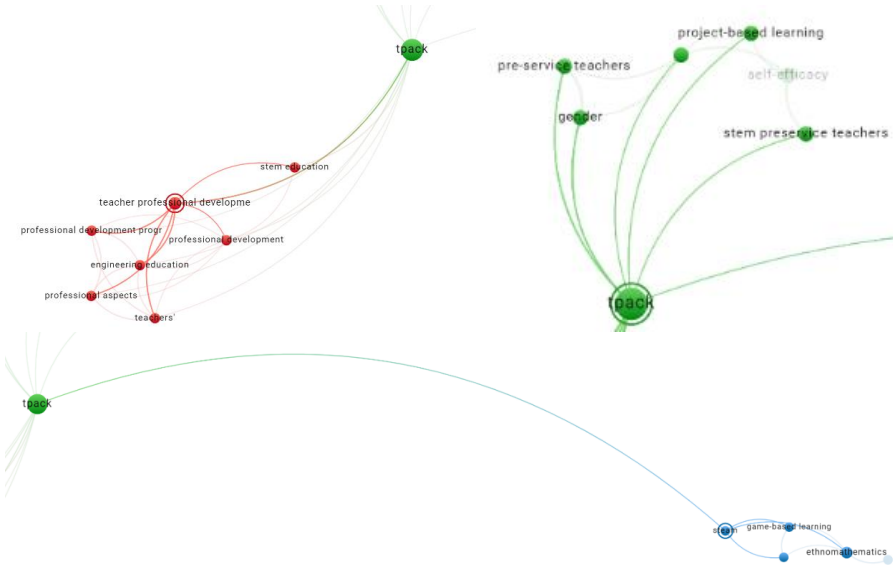


**Figure 7**. Three keyword clusters.

Figure 6 displays the keyword map, and Figure 7 illustrates the three main keyword clusters. This analysis is crucial for understanding the relationships between keywords and concepts in the literature, determining the proximity of keyword groups, tracking trends, and aiding in keyword

selection.

Figure 7 illustrates three distinct clusters identified through keyword mapping. The first cluster includes keywords such as "STEM education", "teacher", and "professional development", indicating a strong connection between STEM education and enhancing teacher professionalism. Cluster 2 features keywords like "pre-service teacher", "TPACK", and "project-based learning", highlighting the importance of integrating TPACK skills into pre-service teacher education. Cluster 3 showcases keywords such as "STEAM", "STEAM education", and "ethnomathematics", revealing a close relationship between STEAM and ethnomathematics. This keyword map provided valuable insights for researchers seeking to understand the research focus in the selected literature.

The visualized data highlights key trends in STEM/STEAM education research. TPACK is a central focus, emphasizing the integration of technology, pedagogy, and content in teaching and learning. Teacher professional development is crucial for enhancing teachers' ability to incorporate technology and innovative teaching methods. Interdisciplinary approaches, such as STEM/STEAM education, are prominent, with game-based learning and project-based learning (PjBL) as popular strategies to enhance student engagement and develop 21st-century skills [37,38].

The focus on ethnomathematics and traditional games in education highlights the integration of cultural elements into learning, particularly in mathematics. The emphasis on pre-service teacher training also underscores the significance of equipping future educators with the necessary skills for technology-based instruction [39,40]. This research trend underscores the importance of developing interactive, contextual, and culturally relevant learning methods to address the complexities of contemporary education, with a particular focus on teacher preparation and the integration of technology in diverse cultural settings.

**Table 3**. Clusters, keywords, frequency of occurrence, and total link strength.

| Cluster | Keywords | Occurrences | Total link strength |
|---|---|---|---|
| Cluster 1 | engineering education | 2 | 10 |
| | professional aspects | 2 | 10 |
| | professional development program | 2 | 10 |
| | professional development | 2 | 7 |
| | stem education | 2 | 4 |
| | teacher professional development | 3 | 12 |
| | teachers’ | 2 | 10 |
| Cluster 2 | Gender | 2 | 5 |
| | pre-service teachers | 2 | 5 |
| | project-based learning | 2 | 3 |
| | self-efficacy | 2 | 3 |
| | STEM pre-service teachers | 2 | 2 |
| | technological pedagogical content knowledge | 2 | 5 |
| | TPACK | 9 | 17 |
| Cluster 3 | Ethnomathematics | 3 | 5 |
| | game-based learning | 2 | 4 |
| | STEAM | 2 | 4 |
| | STEAM education | 2 | 2 |
| | traditional games | 2 | 4 |

Table 3 presents the details of the keywords in each cluster, including their frequency and link strength, as shown in Figures 5 and 6. The keywords in the first cluster have varying frequencies of occurrence. "Teacher professional development" has the highest frequency at three, while other keywords have a frequency of two. The total links for each keyword in the first cluster are relatively high, indicating a strong relationship between them. "Teacher professional development" has the highest total links at 12. In the second cluster, "TPACK" has the highest frequency of occurrence (9) with 17 links. In the third cluster, "ethnomathematics" has the highest occurrence, with three instances and five links. "STEAM education" in the third cluster and "steam education" in the first cluster both have a frequency of occurrence of two and a total link of four. These results highlight how the selected studies focused on improving teacher professionalism, TPACK, STEAM education, and ethnomathematics.

In this section, researchers analyzed the content of the selected literature to address the research questions. The study focused on examining the relationship between project-based learning designs that incorporate ethnomathematics and STEAM and the professional development of future teachers' TPACK abilities. The findings of the analysis are outlined in Table 4.

**Table 4.** Studies on TPACK, STEM/STEAM, and ethnomathematics.

| Author(s) | Year | Participant | TPACK framework | STEM/STEAM framework | Ethnomathematics framework |
|---|---|---|---|---|---|
| Meletiou-Mavrotheris & Paparistodemou | 2024 | Teachers | TPACK: teacher competency | STEM: educational approach | - |
| Mansour N, Said Z, & Abu-Tineh A | 2024 | Teachers | TPACK: teacher competency (CK, PK, PCK, TPCK, TCK) | STEAM: learning approach with PBL | - |
| Karampelas, K. | 2023 | Articles | TPACK: a framework that links technology, pedagogy, and content | STEAM: integrative approach | - |
| Mangundu J | 2023 | Pre-service teachers | TPACK: pre-service teacher competency | STEM: a cluster of courses | - |
| Said Z, Mansour N, & Abu-Tineh A | 2023 | Teachers | TPACK: teacher skills | STEM: integrative approach with PBL | - |
| Huang B. et al. | 2022 | Articles | TPACK: teacher professional development (PK, PCK, TK, and TPCK) | STEM: integrative approach | - |
| Wahono B, Hariyadi S, & Wijaya A. Subiantoro | 2022 | Teachers | TPACK: teacher skills | STEM: integrative approach | - |
| Umutlu D. | 2022 | Pre-service teachers | TPACK: indicators for designing and evaluating courses (TK, TPK, and | STEM: integrative approach | - |

| Author(s) | Year | Participant | TPACK framework | STEM/STEAM framework | Ethnomathematics framework |
|---|---|---|---|---|---|
| | | | TPACK) | | |
| Morales M. et al. | 2022 | Teachers | TPACK: teacher knowledge (technology, pedagogy, content) | STEM: a cluster of courses | Culture: context |
| Irwanto I, Redhana, & Wahono | 2022 | Pre-service teachers | TPACK: knowledge of technology, pedagogy, and content. | STEM: integrative approach | - |
| Nieto C. & Alsina A. | 2022 | Artisans | - | STEAM: integrative approach | Culture: context |
| Chaipidech P. & Srisawasdi N | 2021 | Teachers | TPACK: teacher knowledge (technology integration in learning) | STEM: integrative approach | - |
| Oliveras A, Gámez A, & Oliveras M. | 2021 | Children (8–12 years old) | - | STEAM: integrative approach | Culture: context |
| Schmid M, Brianza E, & Petko D | 2021 | Pre-service teachers | TPACK: pre-service teachers' abilities (TK, CK, PK, TCK, PCK, TPK, and TPCK) | STEM: a cluster of courses | - |
| Thierry Dana-Picard, Sara Hershkovitz | 2020 | Pre-service teachers | - | STEAM: integrative approach | Culture: context |
| Gámez M, Oliveras A, & Oliveras M. | 2020 | Students (5–12 years old) | - | STEAM: integrative approach | Culture: context |
| Nursyahaidah F & Mulyaningrum E. | 2022 | Articles | TPACK: pedagogical and technological knowledge | STEM: integrative approach | - |

Table 4 shows that the reviewed studies reflect varying conceptual configurations rather than a unified instructional model. Most TPACK-related studies position TPACK as a framework for assessing teacher competencies in STEM/STEAM contexts. In contrast, studies emphasizing ethnomathematics or cultural perspectives typically use culture as a contextual background rather than as a structured technological-pedagogical design framework. Project-based learning, when present, is generally linked to STEM instructional practice but rarely combined with both ethnocultural design and TPACK simultaneously. Conceptually, 16 of the 17 studies explicitly address STEM or STEAM, 11 include TPACK as a framework for examining teacher knowledge or competencies, 4 foreground ethnomathematics or cultural contexts, and only 3 incorporate

project-based learning. This distribution illustrates that STEM/STEAM–TPACK constitutes the dominant research pairing, while culturally grounded and project-based configurations appear less frequently.

## 4. Discussion

This discussion synthesizes evidence from the 17 included studies to address the research question, with particular attention to how PjBL, ethnomathematics, STEM/STEAM, and TPACK intersect within the reviewed literature. Importantly, the synthesis indicates that these elements are not consistently integrated within a single instructional design across the corpus; instead, studies reflect varying configurations and emphases.

### 4.1. RQ1. Research trends in STEM/STEAM, ethnomathematics, PjBL, and TPACK (2018–2024)

The synthesis of the reviewed studies indicates that research from 2018 to 2024 is predominantly centered on STEM/STEAM and TPACK within pre-service mathematics teacher education. Sixteen of seventeen studies explicitly address STEM or STEAM as an interdisciplinary or integrative educational approach, while eleven studies focus on TPACK as a framework for examining teachers' professional knowledge, competencies, or readiness for technology integration. This pattern suggests that STEM/STEAM–TPACK has emerged as a dominant analytical lens in recent literature.

In contrast, ethnomathematics or explicit cultural contexts appear in a smaller subset of studies. Ethnomathematics is generally introduced as a contextual element that enriches the learning experience, such as through traditional games, local artifacts, or culturally rooted mathematical practices [41]. However, these studies remain fewer in number, indicating that ethnomathematics and cultural integration occupy a more peripheral position compared to STEM/STEAM and TPACK.

Temporally, the distribution of publications shows a notable concentration in the later years of the interval, particularly around 2022, reflecting increasing scholarly attention to interdisciplinary and technology-integrated approaches in teacher education. Geographically, the studies span multiple national contexts, with recurring contributions from Indonesia and several other countries, suggesting both regional specificity and broader international engagement. Methodologically, the literature is characterized by diverse approaches, including quantitative surveys and quasi-experimental designs, qualitative case studies, bibliometric analysis, and systematic reviews, with TPACK-focused studies often adopting evaluative or measurement-oriented designs.

### 4.2. RQ2. Conceptualization and positioning of PjBL, ethno–STEAM perspective, and TPACK

An analysis of how PjBL, ethno–STEAM perspective, and TPACK are conceptualized and positioned across the reviewed studies reveals a largely fragmented landscape. While STEM/STEAM and TPACK frequently co-occur, PjBL and ethnomathematics or cultural perspectives are incorporated less consistently and often independently of one another.

PjBL appears in only a small number of studies and is typically positioned as a pedagogical strategy for enacting STEM learning or fostering active engagement. In these cases, PjBL is often associated with examining teachers' competencies, self-efficacy, or instructional practices related to technology integration, aligning conceptually with TPACK. PjBL is rarely framed within an explicit

ethno–STEAM perspective that systematically integrates cultural contexts into project design.

Conversely, studies emphasizing ethnomathematics or cultural contexts tend to frame culture as a meaningful learning context rather than as a structured pedagogical or technological design framework. Cultural elements are used to contextualize mathematical or scientific concepts and enhance student engagement, yet these seldom operationalize TPACK as an analytical or development construct. Notably, none of the reviewed studies explicitly integrates TPACK with ethnomathematics or cultural perspective, and no study simultaneously combines STEM/STEAM, PjBL, ethnocultural design, and TPACK within a single coherent instructional model.

Overall, the reviewed literature positions STEM/STEAM–TPACK as a relatively mature research area, particularly in terms of assessment and professional or contextual approaches rather than fully integrated components. This configuration suggests that the conceptual intersection of PjBL, ethno–STEAM perspective, and TPACK remains underdeveloped in empirical research.

### 4.3. RQ3. Gaps, challenges, and implications for developing PjBL–ethno–STEAM

The synthesis highlights several gaps and challenges that inform future research opportunities and implications for the development of PjBL–ethno–STEAM in pre-service mathematics teachers' education. First, there is a clear absence of empirically tested instructional models that intentionally integrate STEM/STEAM, ethnomathematics or cultural contexts, project-based learning, and TPACK within a unified design framework. While each component is addressed individually or in partial combinations, holistic integration remains largely conceptual.

Second, although TPACK is frequently measured as an outcome variable, few studies provide detailed descriptions of instructional processes that support TPACK development in culturally grounded and project-oriented learning environments. This limits the understanding of how pre-service teachers learn to integrate content, pedagogy, technology, and cultural context in practice. Third, the limited and inconsistent use of PjBL/PBL within culturally grounded STEM/STEAM contexts suggests a need for clearer theorization and design principles that articulate how project-based learning can function as a bridge between ethno–STEAM perspectives and TPACK development. Addressing these gaps would require future studies to adopt design-based or intervention-oriented approaches that explicitly examine how culturally contextualized projects, supported by appropriate technological tools, contribute to pre-service teachers' professional knowledge development.

Taken together, these findings suggest that PjBL–ethno–STEAM should be viewed as an emerging and promising direction rather than a well-established instructional model. Future research that systematically integrates these dimensions has the potential to strengthen the theoretical coherence and practical relevance of mathematics teachers' education programs, particularly in preparing pre-service teachers to design learning experiences that are both technologically responsive and culturally meaningful.

### 4.4. Gaps, implications, and recommendations for future research

The studies examined two perspectives on STEM/STEAM: as a learning approach and as a group of subjects. This study specifically focuses on STEM/STEAM as a framework for a learning approach. Existing research primarily emphasizes the implementation of STEM or the integration of STEAM, with limited consideration of a cultural context. Five studies incorporated cultural context

into STEM/STEAM [23,42–45], involving diverse participants such as children aged 5–12, artisans, and pre-service teachers. Only one study focused on pre-service teachers [44], but it did not provide clear guidance on how to integrate cultural context into learning. Meanwhile, effective implementation of STEM/STEAM requires a well-defined learning design for teachers to follow [46] a strategy to integrate technology in learning [47], and also policy, support, and school leadership that affect teacher performance [48].

Integrating culture into STEAM education, often referred to as ethno–STEAM, has been discussed in the literature as a promising approach for supporting the development of 21st-century skills. STEAM learning is frequently associated with professional learning opportunities for teachers and future educators, with TPACK skills commonly used as an indicator of teacher knowledge. Several studies report connections between STEAM education and TPACK development among teachers and pre-service educators. However, the review indicates a notable gap in understanding how pre-service teachers may develop their TPACK competencies through culturally integrated, project-based learning contexts.

One overlooked challenge is how pre-service teachers can effectively integrate technology, pedagogy, content, and culture in their teaching. Although some studies have examined teachers' TPACK skills in technology use, there is a lack of research on the connection between PjBL–ethno–STEM and the development of pre-service teachers' TPACK. Thus, further research is required to explore the benefits of this approach in teacher education. Table 5 outlines the key aspects, focus areas, and research gaps for future studies.

**Table 5.** Aspects, focus areas, and research gaps for future studies.

| Aspect | Current research focus | Research gaps |
|---|---|---|
| STEM/STEAM | STEM/STEAM research is seen as a learning approach and a group of courses. STEAM is integrated with culture, where the cultural context is a bridge to mathematics. | There is still no clear learning design on how to integrate cultural context in STEAM learning |
| Relation to TPACK | Several studies measure TPACK competency in STEM learning for STEM/STEAM teachers and mathematics teachers. | There are not many studies that explore the specific relationship between ethno–STEM/STEAM and improving TPACK skills for pre-service teachers. |
| Local culture-based approach | Focus on the application of STEM/STEAM that is more global and does not focus on the local cultural context. | There is a lack of studies on the application of STEM/STEAM with local cultural contexts in developing pre-service teacher competencies. |
| Pre-service teacher readiness | The readiness of pre-service teachers in the application of STEM is often measured technically. | There is still a lack of research that discusses pre-service teachers' readiness to integrate technology, pedagogy, and culture. |
| Barriers to technology integration | Barriers to technology integration are more discussed in the general context of the application of technology in the classroom. | There is still limited research that identifies challenges in the simultaneous integration of TPACK, technology, and culture. |

Table 5 reveals several implications. First, there is a need for a more in-depth exploration of the application of STEAM in learning. Second, further exploration of TPACK in relation to STEM/STEAM is crucial, as the development of TPACK is essential for pre-service teachers, and

STEM/STEAM can enhance it. Third, it is essential to explore local cultural aspects in greater depth to enhance TPACK for pre-service teachers. Finally, discussing the readiness and obstacles to technology integration for pre-service teachers is vital, as effective learning hinges on teacher readiness and overcoming potential obstacles.

## 5. Conclusions

This study conducted a systematic literature review examining how STEM/STEAM, ethnomathematics, project-based learning, and TPACK are positioned in research related to pre-service mathematics teacher education. The synthesis suggests that project-based ethno–STEAM represents a promising conceptual direction for integrating technology, pedagogy, and content in culturally contextualized ways. This configuration highlights potential pathways for connecting theory and practice and for situating learning experiences within relevant local cultural contexts.

However, the review also identifies several research gaps. Limited studies explicitly examine the relationship between project-based ethno–STEAM configurations and TPACK development in pre-service teachers. Most research focuses on project-based learning or STEM/STEAM independently, without systematically integrating local cultural perspectives and TPACK. In addition, there is limited discussion of the practical challenges that pre-service teachers may encounter when attempting to integrate technology, pedagogy, content, and cultural contexts simultaneously.

Although project-based ethno–STEAM can be conceptually framed as a novel integrative perspective, further empirical research is needed to explore how such a configuration may be designed, implemented, and studied in teacher education contexts. Future studies may therefore investigate culturally contextualized STEM/STEAM learning designs and examine the challenges that pre-service teachers face when working within technology-integrated and ethnocultural learning environments.

## Author contributions

Dwi Astuti: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing - original draft, & Writing - review & editing; Heri Retnawati: Funding acquisition, Supervision, Writing - review & editing; Rully Charitas Indra Prahmana: Supervision, Validation, Writing - review & editing; Ahmad Naufal Aljura: Supervision, Validation, Writing - original draft, & Writing - review & editing; Septinda Rima Dewanti: Supervision, Validation, Writing - review & editing; Gulzhaina Kuralbayevna Kassymova: Supervision, Validation, Writing - review & editing.

## Use of Generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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## Conflict of interest

The authors declare that there is no conflict of interest in this manuscript.

## Ethics declaration

The author declared that no ethics approval is required for the study.

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