MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2026, 22(7), em2868
ISSN:1305-8223 (online)
OPEN ACCESS Literature Review https://doi.org/10.29333/ejmste/18868

Teachers' STEAM competencies for the 21st century: A systematic review

Cheng Jingwen [1], Riyan Hidayat [1,2*], Muhammad Zarif Bin Hassan @ Zulkifli [1]

[1] Faculty of Educational Studies, Universiti Putra Malaysia, Selangor, MALAYSIA
[2] Faculty of Education, Languages, Psychology & Music, SEGi University, Selangor, MALAYSIA

Received 26 January 2026 ▪ Accepted 19 June 2026

Abstract

The present study conducts a systematic review of teachers' STEM/STEAM competencies. Following PRISMA guidelines, 28 peer-reviewed studies were retrieved from Web of Science, ERIC, Google Scholar, and Scopus. The review synthesizes major competency domains and sub-dimensions, examines existing competency frameworks, and analyzes the geographic distribution of related research. The findings reveal a strong emphasis on competency classification but show limited empirical validation of existing models and frameworks. Furthermore, this review also identifies insufficient elaboration of arts-related competencies and significant regional imbalances, with most studies concentrated in East and Southeast Asia. Three major gaps emerged: the underrepresentation of arts-related competencies, the limited availability of validated competency models, and uneven regional representation. Existing frameworks frequently combine aesthetic literacy, creative instructional design, and arts-integrated pedagogical practice into a single category. Consequently, professional development programs often emphasize generalized creativity training while neglecting disciplinary arts knowledge and pedagogical practices essential for authentic STEAM integration.

Keywords: competency frameworks, interdisciplinary teaching, STEAM education, systematic review, teacher competencies

INTRODUCTION

STEAM education has gained increasing attention as an approach to prepare students for the complex demands of the 21st century (Boice et al., 2021; Mohd Saad et al., 2023; Xenakis, 2025). By integrating the arts into STEM, STEAM promotes synergy between scientific and creative disciplines and supports the development of the "whole child." Unlike traditional, subject-isolated instruction, STEAM emphasizes interdisciplinary, real-world learning experiences that foster creativity, innovation, and holistic understanding (Herro et al., 2019). Consequently, STEAM education has become increasingly vital across educational levels, from primary to higher education, as a means of cultivating diverse competencies required in contemporary society.

Although STEAM education is widely recognized for fostering creativity, critical thinking, and problem-solving skills (Hendriyanto et al., 2024; Ortiz-Revilla et al., 2023), its implementation remains uneven and fragmented. This is largely due to teacher education approaches constrained by rigid disciplinary boundaries which leave educators insufficiently prepared for interdisciplinary practice (So et al., 2019; Spyropoulou et al., 2025a, 20205b). While recent scholarship has advanced the development of competency frameworks, including interdisciplinary integration models (Song, 2017), context-based frameworks (Alcaraz-Dominguez & Molas-Castells, 2024; Spyropoulou & Kameas, 2023), and evaluation index systems (Kim & Kim, 2016) , these efforts remain limited in scope. They typically address isolated competency dimensions without comprehensively capturing multidisciplinary integration or creative outcomes. Compounding this challenge, the construct of "competency" itself lacks definitional consistency, frequently oscillating between subject knowledge, interdisciplinary teaching skills, and dispositional attitudes toward integration (Spyropoulou & Kameas, 2023). Moreover, divergent interpretations of STEAM further constrain cross-contextual comparability and framework transferability (Jiayuan & Hidayat, 2025; Leavy et al., 2023).

✉ vickycheng0204@gmail.com ✉ riyan160989@gmail.com **(*Correspondence)** ✉ riyan6095@gmail.com

Contribution to the literature

- This study contributes to the existing body of literature and empirical research on teachers' STEM and STEAM competencies by addressing identified gaps, with a particular emphasis on core competency domains, their constituent sub dimensions, and the associated theoretical models and frameworks that underpin them.
- It identifies key conceptual limitations in current studies, including inconsistent competency classifications, limited empirically validated frameworks, and insufficient integration of arts-related competencies within STEAM.
- The review highlights uneven geographic distribution of research, emphasizing the need for contextually responsive and globally inclusive studies to enhance teachers' STEM/STEAM competency development.

Previous systematic reviews on STEAM education have primarily emphasized student outcomes and curriculum implementation. This leaves teacher competencies comparatively underexplored and insufficiently validated empirically (Alcaraz-Dominguez & Molas-Castells, 2024 ; Deák & Kumar, 2024; Heung et al., 2024). Arts-related competencies remain inadequately integrated within existing STEAM frameworks, creating a structural imbalance that challenges the interdisciplinary foundations of STEAM education (Alcaraz-Dominguez & Molas-Castells, 2024). Furthermore, fragmented competency frameworks and inconsistent conceptual definitions hinder the identification of coherent competency requirements for effective teaching. To address these gaps, this study conducts a systematic literature review to synthesize key competency dimensions, sub-dimensions, and frameworks for STEAM teacher development.

Research Questions

1. What are the key areas involved in the development of teachers' STEAM competencies?
2. What are the main sub-dimensions that constitute teachers' STEAM competencies?
3. What are the major models developed to describe or assess STEAM competencies in teachers?
4. What are the primary frameworks proposed for guiding the development of teachers' STEAM competencies?
5. What is the geographical distribution of educators or researchers involved in studies on teachers' STEAM competencies?

THEORETICAL FOUNDATION

Constructivism Learning Theory and STEM/STEAM

Constructivist learning theory conceptualizes learning as an active process in which learners construct knowledge through prior experience and interaction with their environment (Nurhuda et al., 2023). This perspective underpins student-centered approaches such as project-based, inquiry-based, and collaborative learning, which are widely adopted in contemporary education (Hidayat et al., 2024; Mir et al., 2025). In STEAM education, effective implementation depends not only on disciplinary content mastery but also on constructivist pedagogical practices that support authentic and experiential learning. Prior studies identify project-based learning as one of the most coherent approaches for STEAM development (Diego-Mantecon et al., 2021), while inquiry-based teaching further emphasizes student autonomy, exploration, and teacher facilitation through real-world learning experiences (Başaran & Vural, 2025; Mei et al., 2025).

Constructivist-oriented STEAM teaching positions teachers as facilitators responsible for designing authentic learning environments. However, teachers frequently encounter barriers to STEAM implementation, including limited content knowledge, insufficient time, inadequate professional training, and high implementation costs. All these factors constrain effective student engagement. Existing research suggests that the success of constructivist STEAM learning largely depends on teachers' conceptual understanding and practical competencies in managing interdisciplinary and complex learning contexts. STEAM tasks require students to draw on prior knowledge from multiple disciplines. As such, teachers must demonstrate integrated knowledge across science, technology, engineering, arts, and mathematics to respond flexibly to diverse learning needs (Caner & Ogan-Bekiroglu, 2025). Although integrated training programs may enhance teacher competency, current studies provide limited empirical evidence on how teachers develop and enact constructivist STEAM competencies in authentic classroom settings. This highlights the need for more systematic research on the development and application of teacher competency within constructivist STEAM education.

STEM/STEAM Competencies for Teachers

McClelland (1973) defined competency as knowledge, skills, abilities, traits, and motivations associated with effective job performance. Competency therefore represents a combination of knowledge, skills, attitudes, and experience that enables individuals to perform successfully. In teaching, competency involves

Table 1. Keyword search strategy

Keyword	The strings and combinations of keywords
Teacher STEM/STEAM competency	("Teacher STEM Competency" OR "Teacher STEAM Competency") AND
Teacher STEM/STEAM competency model	("Teacher STEM Competency Model" OR "Teacher STEAM Competency Model") AND
Teacher STEM/STEAM competency framework	("Teacher STEM Competency Framework" OR "Teacher STEAM Competency Framework")

not only possessing knowledge and skills but also applying them flexibly and purposefully in complex classroom situations. Spyropoulou and Kameas (2023) categorized teacher competence into knowledge, skills, and dispositions. Based on these perspectives, this review defines STEAM teacher competencies as an integrated system of interdisciplinary knowledge, pedagogical and technological skills, professional qualities, and identity-based orientations that support interdisciplinary learning design and evaluation.

The TPACK framework (Mishra & Koehler, 2006), which explains how teachers integrate technological, pedagogical, and content knowledge, has been widely applied to assess teacher competency in STEM education, with publications linking TPACK to teacher training, science education, and digital tools increasing rapidly (B. Huang et al., 2022; Karampelas, 2023, 2026; Zhuofan et al., 2024). Complementing this knowledge-oriented perspective, Galanti and Holincheck (2022) proposed an integrated STEM teacher identity model that connects motivation, self-efficacy, recognition and competency. This model positions teachers' self-perception as interdisciplinary educators as a critical driver of long-term competency development and sustained commitment to STEM teaching (El Nagdi et al., 2018; Holincheck & Galanti, 2023). While TPACK illuminates the knowledge dimension of teacher competency and the integrated STEM teacher identity model addresses its dispositional and identity dimension, both frameworks remain largely confined to STEM contexts. Although recent efforts have begun to develop instruments measuring primary school teachers' self-efficacy in STEAM teaching (Ilić et al., 2025), the distinctive role of arts integration in shaping teacher identity remains underexplored, and research on STEAM-specific teacher identity is correspondingly limited. This review addresses that gap by systematically identifying competency dimensions that should inform future STEAM teacher identity research and framework development.

Recent studies have proposed diverse STEM/STEAM teacher competency frameworks from multiple theoretical perspectives. Early frameworks emphasized observable teaching competencies, including subject understanding, pedagogy, learner support, assessment and personal teacher qualities (Kim & Kim, 2016). In contrast, TPACK-oriented research highlights the integration of technology, pedagogy and content knowledge, although balancing these components remains a persistent challenge. Other frameworks adopt skills and literacy-based perspectives that emphasize digital competence, research skills and soft skills, yet these often lack coherent theoretical integration (Li et al., 2020; Machado et al., 2022; Morze & Strutynska, 2021; Ortiz-Laso et al., 2023). More recent studies increasingly emphasize teacher roles, professional identity, self-efficacy, motivation and interdisciplinary teaching engagement as central dimensions of STEAM competency development (Holincheck & Galanti, 2022; Spyropoulou & Kameas, 2023).

METHODOLOGY

This study employs a systematic review to ensure a transparent, structured and methodologically rigorous synthesis of existing research (Hendriyanto et al., 2023; Hidayat & Wardat, 2023). The review synthesizes key competency dimensions, models and frameworks identified through systematic searches of Web of Science (WoS), ERIC, Scopus and Google Scholar. WoS and ERIC were selected for their authoritative education-focused coverage, while Scopus provided broad interdisciplinary indexing and Google Scholar expanded access to diverse, grey and multilingual academic sources. To capture recent developments in global STEAM education policy and curriculum reform, studies published between 2016 and 2025 were targeted. The search strategy applied Boolean operators and truncation techniques across titles, abstracts and keywords to maximize literature coverage (**Table 1**).

We utilized the PRISMA framework which consists of four sequential stages: identification, screening, eligibility assessment, and inclusion.

Identification

The search targeted keywords related to STEM/STEAM teacher competencies, competency models, and competency frameworks across titles, abstracts and keywords, covering both journal articles and conference-related publications. To improve comprehensiveness, forward and backward citation tracking were applied. Backward snowballing was used to identify additional relevant studies through references and citing articles (Hidayat et al., 2022; Tahiru, 2021). The initial search yielded 7,875 records,

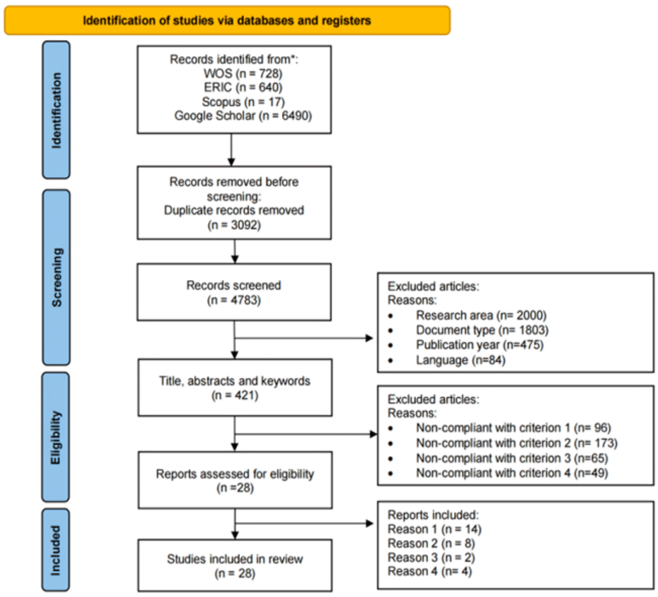

Figure 1. PRISMA protocol chart (the authors' own elaboration)

including 728 from WoS, 640 from ERIC, 17 from Scopus, and 6,490 from Google Scholar, which were subsequently screened for relevance and quality.

Screening

Of the 7,875 records initially identified, 3,092 duplicates were removed following the PRISMA protocol (**Figure 1**). The remaining studies were screened according to predefined inclusion criteria, including relevance to STEM/STEAM teacher competencies, publication year, document type, language and full-text availability. To ensure contemporary relevance, only English-language studies published between 2016 and 2025 were included, while inaccessible or non-English publications were excluded. After screening, a further 4,362 records were removed, resulting in the final dataset for eligibility assessment. All studies included at this stage were retrieved in full text from the targeted databases.

Eligibility

During the eligibility phase, the remaining 421 records were manually reviewed to ensure alignment with the predefined inclusion criteria. The following formal inclusion criteria were applied:

1. The article has a relevant title and is related to the selected topic while the key search terms appear in the article's title, abstract, and keywords.
2. The article focuses predominantly on teacher competencies than on student competencies.
3. For studies that include competency frameworks, the main focus is on integrated STEM/STEAM.
4. For studies that include competency models, the main focus is on integrated STEM/STEAM.

Through this manual evaluation process, a total of 96 articles were excluded for failing to meet criterion 1,173 for failing to meet criterion 2, 65 for failing to meet criterion 3, and 49 for failing to meet Criterion 4. Following this detailed evaluation, 28 full-text articles were retained for a detailed review. The main search terms guiding this phase included "teachers' STEM/STEAM competencies," "teachers' STEM/STEAM competency models," and "teachers' STEM/STEAM competency frameworks."

Inclusion

A final total of 28 articles were selected for inclusion in this study. All included data were drawn from peer-reviewed journal articles, given their established advantages in terms of accessibility, timeliness and reliability.

Data Analysis

To further ensure the rigor and validity of the review, the included studies were evaluated and ranked prior to inclusion, resulting in a final dataset drawn from 28 publications. Each article was carefully analyzed with respect to its introduction, objectives, research questions, methodology, key findings and discussion sections. Concurrently, to ensure the methodological rigor of the included studies, this study employed the mixed methods assessment tool (MMAT) for quality assessment. This tool is suitable for evaluating a variety of research designs, including qualitative, quantitative, and mixed-methods studies (Hong et al., 2018; Utami et la., 2024). Each included study was assessed against the criteria relevant to its specific design type, including clarity of research objectives, methodological appropriateness, validity of data collection and consistency of findings (Hong et al., 2019).

To ensure systematic and consistent data extraction from the 28 included studies, the researchers utilized a data extraction form to collect bibliographic details (authors, year, country, and journal), research design and methods, participant characteristics and sample size, theoretical frameworks, identified competency domains and sub-dimensions and key findings relevant to the review questions. A thematic synthesis method was applied following Thomas and Harden (2008), which involved line-by-line coding, development of descriptive themes, and generation of analytical themes. Two researchers independently conducted screening and coding, while a third reviewer checked 20% of records to ensure consistency. Disagreements were resolved through consensus and inter-coder reliability was measured using Cohen's kappa ($\kappa \geq 0.80$). Themes were iteratively refined until thematic saturation was reached and verified against original studies.

Table 2. Systematic literature review summary

No	Author	Subject	Types of teacher STEM/STEAM competencies (main competencies/sub-dimensions/major model/framework)
1	Morze and Strutynska (2021)	STEAM	Teacher STEAM main competencies – sub-dimensions – model
2	So et al. (2019)	STEAM	Teacher STEAM main competencies – sub-dimensions
3	Spyropoulou and Kameas (2023)	STEAM	Teacher STEAM competencies framework
4	Kim and Kim (2016)	STEAM	Teacher STEAM main competencies – sub-dimensions
5	Ortiz-Laso et al. (2023)	M	Mathematics competencies
6	Morales et al. (2020)	STEAM	Philippine professional standards for teachers (PPST)
7	Song (2017)	STEM	Teacher STEM main competencies – sub-dimensions
8	Bushey (2024)	STEAM	Global competence in STEAM Fields
9	Oanh (2024)	STEM	Teacher STEM competence framework
10	ElSayary et al. (2022)	STEAM	Teacher STEAM main competencies
11	Song (2019)	STEM	Teacher STEM main competencies – sub-dimensions
12	Spyropoulou and Kameas (2021)	STEAM	Teacher STEAM main competencies – sub-dimensions
13	Machado et al. (2022)	TM	Competencies for STEAM areas
14	Wiegand and Rita (2023)	M	Mathematical modelling
15	Morales et al. (2020)	STEAM	Teacher STEAM main competencies – sub-dimensions
16	Hu and Guo (2021)	STEM	Teacher STEM main competencies
17	Holincheck and Galanti (2023)	STEM	STEM teacher identity
18	Bedewy and Lavicza (2023)	STEAM+X	Teacher STEAM main competencies – sub-dimensions
19	Vaz-Rebelo et al. (2025)	STEAM	Teacher STEAM main competencies
20	Ergül (2021)	STEM	Teacher STEM main competencies – sub-dimensions
21	Rüütmann (2023)	E	Teacher STEAM engineering competencies
22	Chamrat and Suyamoon (2024)	STEM	Teacher STEM main competencies
23	Caner and Ogan-Bekiroglu (2025)	STEM	Teacher STEM main competencies – sub-dimensions
24	Marlina et al. (2025)	Biology-STEM	Biology teacher STEM competencies
25	B. Huang et al. (2022)	STEM	Teacher STEM main competencies – sub-dimensions
26	Le et al. (2025)	STEM	Teacher STEM main competencies – competencies framework
27	Valentová and Brečka, (2025)	T	Technical competencies
28	Radvila et al. (2025)	STEAM	Teacher STEAM conceptual framework

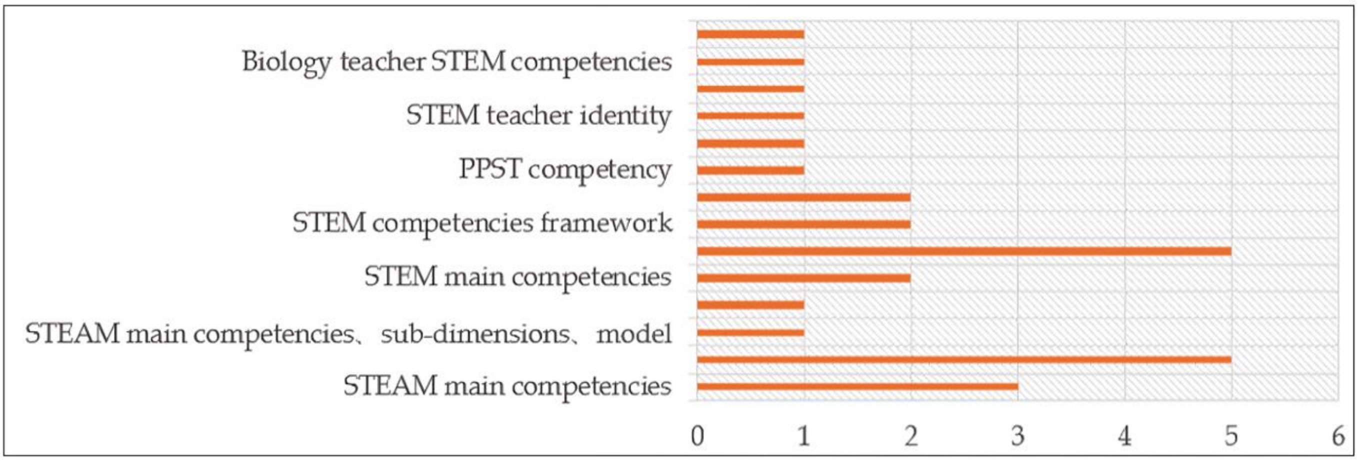

Figure 2. Distribution of article topics (the authors' own elaboration)

FINDINGS OF SYSTEMATIC LITERATURE REVIEW

This section presents the findings from the data synthesis and analysis. Following the screening process, a total of 26 articles were included in the systematic review. The analysis was guided by five research questions, which informed the examination of all selected studies. **Table 2** provides a comprehensive summary of all records retained.

Descriptive Results

Figure 2 and **Figure 3** show that research on STEM/STEAM teacher competencies is predominantly centered on core competency domains and their sub-dimensions, specifically teachers' STEM and STEAM competencies (n = 5 each). Other frequently discussed themes included STEAM competencies (n = 3), STEM competencies and competency frameworks (n = 2 each), and mathematics-related competencies (n = 2). Overall, STEAM (n = 11) and STEM (n = 10) dominate the

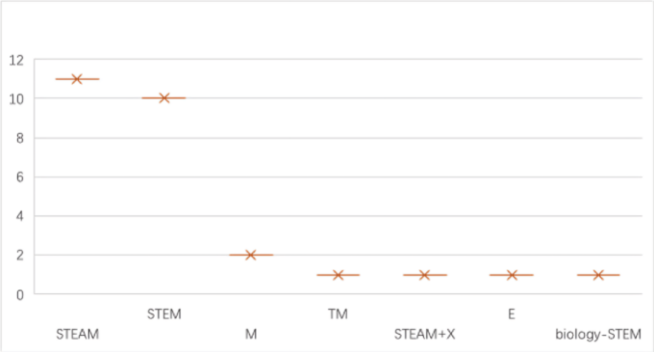

Figure 3. Distribution of article subjects (the authors' own elaboration)

literature, while discipline-specific areas such as mathematics, TM, STEAM+X, engineering, biology-STEM, and technology received comparatively limited attention.

While the literature increasingly underscores the importance of integrated and interdisciplinary competencies, the continued presence of discipline-specific studies suggests that disciplinary depth remains essential in teacher competency research. This also indicates a limitation of unified competency frameworks, which may inadequately capture the subject-specific knowledge structures and pedagogical practices required in individual disciplines. For example, mathematical modelling competency is grounded in the internal logic of mathematics and involves highly specialized sub-competencies which are difficult to fully represent within generalized STEM/STEAM frameworks (Ortiz-Laso et al., 2023; Wiegand & Rita, 2023).

Teacher STEM/STEAM Main Competencies

The distribution of studies addressing teachers' STEM and STEAM main competencies is presented in **Appendix A**. Analysis of the reviewed studies reveals several common patterns in STEM/STEAM teacher competency across national contexts. Content knowledge, whether framed as scientific understanding, content expertise or skill mastery, is consistently identified as foundational due to the interdisciplinary nature of STEAM education (ElSayary et al., 2022; Hu & Guo, 2021; Le et al., 2025). Student-centered, inquiry-based and project-oriented pedagogies, alongside technology integration and TPACK-related competencies, also emerge as recurring requirements across STEM and STEAM contexts (Chamrat & Suyamoon, 2024). However, STEAM frameworks extend beyond conventional STEM models by emphasizing affective and dispositional competencies such as creativity, innovation, self-direction and connectedness (ElSayary et al., 2022). This broader orientation is further reflected in studies integrating humanities and arts-related dimensions into STEAM competency frameworks (Vaz-Rebelo et al., 2025).

The distribution of studies on additional STEM and STEAM teacher competencies is shown in **Appendix B**. Critically, Holincheck and Galanti (2023) reframe professional identity – including motivation, self-efficacy, self-image and task perception – as a constitutive rather than peripheral dimension of STEM teacher competency. This reconceptualizes competency as a dynamic, identity-embedded construct developed through continuous professional experience and reflective practice. This identity-oriented perspective is reinforced across disciplinary studies emphasizing collaboration, reflective practice, and a positive professional self-concept (Marlina et al., 2025; Ortiz-Laso et al., 2023). The inclusion of global competency (Bushey, 2024), engineering-specific pedagogical competency (Rüütmann, 2023), and technology-related competencies (Valentová & Brečka, 2025) signals that the scope of STEAM teacher competency is continuously expanding. There is growing recognition that discipline-specific competency articulation represents an equally important, if currently undertheorized, strand of the field.

Teacher STEM/STEAM Main Competencies – Sub-Dimensions Competencies

The distribution of studies on the main and sub-dimensions of STEM and STEAM teacher competencies is presented in **Appendix C**. Although frameworks differ in terminology and scope, STEM competency research consistently reveals a tripartite structure: cognitive dimensions (content knowledge and interdisciplinary understanding), pedagogical dimensions (teaching skills, curriculum design, and assessment) and affective-motivational dimensions (professional attitudes, collaboration, and self-reflection). This convergence appears across studies from Korea (Song, 2017, 2019), Turkey (Caner & Ogan-Bekiroglu, 2025; Ergül, 2021), and China (X. Huang et al., 2022), suggesting a stable core structure regardless of context. More recently, Caner and Ogan-Bekiroglu (2025) introduced "collaboration and engagement" as a distinct domain, emphasizing active interdisciplinary cooperation. This shift highlights the growing recognition that effective STEM teaching depends not only on individual competence but also on sustained collaboration across departments in daily instructional practice.

For STEAM-specific competency frameworks, the range of sub-dimensions is generally broader and more diverse (Kim & Kim, 2016; Spyropoulou & Kameas, 2021). Competencies such as artistic appreciation and creative integration (So et al., 2019), concrete links between art and architecture (Bedewy & Lavicza, 2023) and soft skills (Morze & Strutynska, 2021) reflect

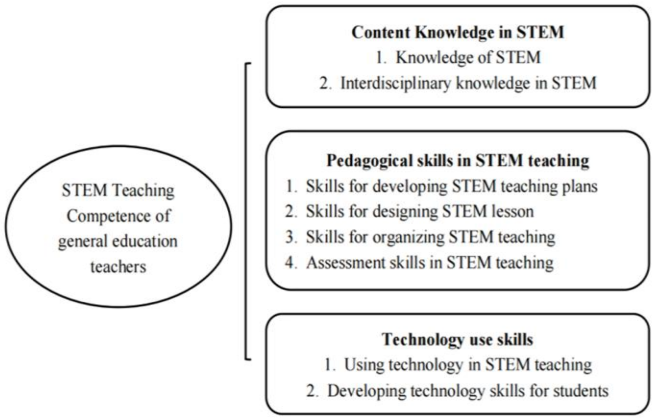

Figure 4. STEM teaching competence model of general education teachers model (Le et al., 2025)

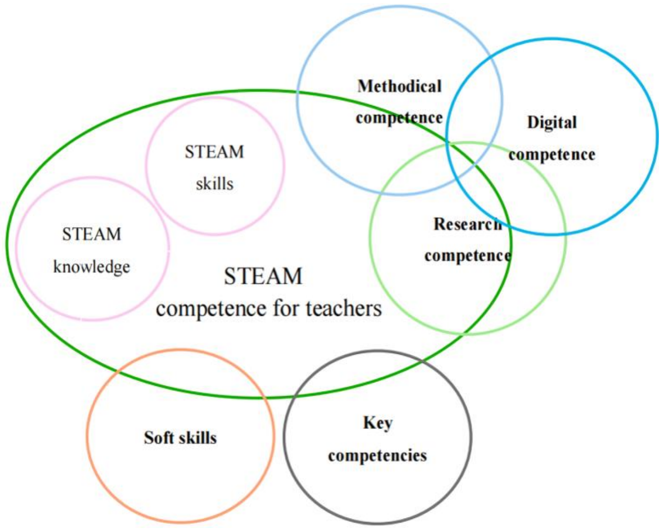

Figure 5. A generalized model of STEAM competence for teachers (Morze & Strutynska, 2021)

expanded professional demands arising from the inclusion of arts in STEM education. However, these arts-related dimensions are frequently listed without clear explanation of how they connect structurally to technological and pedagogical domains.

Additionally, Kim and Kim (2016) highlight understanding learners and contextual conditions, and Spyropoulou and Kameas (2021) frame competencies around design, coordination, and environmental interaction, Morze and Strutynska (2021) treat environmental literacy merely as a sub-element, indicating a lack of consensus on its conceptual status.

A direct comparison between STEM and STEAM teacher competencies reveals both shared characteristics and key differences. Common across both frameworks are disciplinary and interdisciplinary knowledge, pedagogical skills and assessment competencies, suggesting that these form the foundational components of integrated science education teaching (B. Huang et al., 2022; Le et al., 2025; Morze & Strutynska, 2021; Oanh, 2024; Song, 2017). Digital and technological competencies also appear consistently across contexts, reflecting the growing importance of technology integration in STEM/STEAM education (Spyropoulou & Kameas, 2021). In contrast, STEAM frameworks place a vastly stronger emphasis on creative and artistic dimensions. So et al. (2019) specifically identify artistic appreciation and creative integration as core requirements. Meanwhile, STEM frameworks (Ergül, 2021; Song, 2019) focus more narrowly on scientific inquiry and problem-solving, with limited attention to creativity or identity, confirming that the arts remain an underdeveloped competency domain in STEAM research.

Teacher STEM/STEAM Competency Model

Regarding studies on models of teachers' STEM/STEAM competencies, only two primary studies were identified, as illustrated in **Figure 4** and **Figure 5**. Le et al. (2025) proposed a framework for STEM teaching competencies and their constituent elements, which was refined based on expert recommendations. This framework enables general education teachers to self-assess and enhance their instructional skills, thereby improving professional qualifications and addressing students' learning needs. Similarly, Morze and Strutynska (2021) developed a generalized model of STEAM competencies for teachers based on an analysis of its constituent components, providing a structured reference for the development and application of STEAM teaching skills.

Teacher STEM/STEAM Competency Framework

Appendix D and **Appendix E** present frameworks of teachers' STEM/STEAM competencies. Oanh (2024) proposed an integrated STEM competency framework including both tangible and intangible components. The framework highlights collaboration and community-oriented competencies, reflecting the growing consensus that effective STEM teaching is socially constructed through professional learning communities rather than individual practice alone (Caner & Ogan-Bekiroglu, 2025). Although primarily designed as a STEM framework, it encourages teachers to integrate other fields such as the arts, health and AI, and to adopt innovative pedagogies. This indicates both recognition of interdisciplinary expansion and an emerging response to the changing demands of contemporary education, including the gradual inclusion of arts within STEM-oriented teaching practice.

Spyropoulou and Kameas (2023) organized a STEAM competency framework into five perspectives and 16 domains, with a distinctive role-based logic which defines competency through professional roles rather than a checklist of skills. The framework includes multiple teacher identities such as facilitator, learning designer, coordinator, community member, and reflective practitioner, emphasizing collaboration

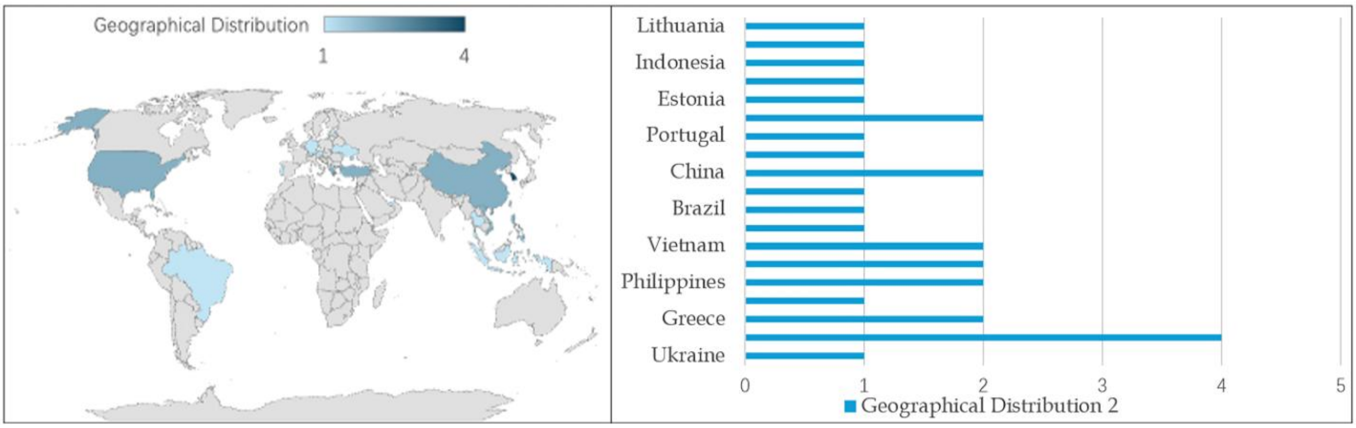

Figure 6. Geographical distribution of STEAM educators or researchers (the authors' own elaboration)

grounded in educators' lived classroom experiences. It highlights continuous professional development and transferable skills, positioning competency as dynamic and evolving rather than fixed. Nonetheless, practical challenges remain, particularly regarding how teachers integrate theoretical knowledge into reflective practice, suggesting a need for research on conditions which support this integration (Vogelsang et al., 2025). Although presented as a STEAM framework, the treatment of the "A" (arts) component is limited, with arts knowledge only briefly acknowledged. This reflects a broader and persistent gap in STEAM competency research.

The analysis of arts-related competencies in STEAM frameworks reveals considerable conceptual inconsistency, with most studies broadly categorizing them as "arts literacy." Existing research generally reflects three dimensions: discipline-specific artistic knowledge, creativity and divergent thinking, and arts-integrated pedagogy. Artistic knowledge commonly includes areas such as literature, drama, music, dance and visual arts, while creativity-related competencies are addressed through concepts such as creative convergence and soft skills (ElSayary et al., 2022; Morze & Strutynska, 2021; So et al., 2019). Though design thinking and arts-integrated pedagogy are frequently recognized in STEAM education (Bedewy & Lavicza, 2023), they are rarely conceptualized as independent, systematically operationalized competency domains. This confirms that arts-related competencies remain insufficiently theorized within current STEAM competency frameworks.

Geographical Distribution of STEAM Educators or Researchers

Figure 6 presents the geographic distribution of studies included in this review, revealing a pronounced concentration in East and Southeast Asia, particularly South Korea (n = 4), Vietnam (n = 2), China (n = 2), and the Philippines (N = 2). This pattern is attributable to structural, policy-driven factors rather than research coincidence. South Korea's disproportionate contribution reflects sustained government investment since 2011, encompassing national curriculum reform, targeted funding and institutionalized K-12 teacher development programs (Kang, 2019; Park & Cho, 2022).

In China, interdisciplinary STEM education has been formally promoted through the 2016 Ministry of Education 13th five-year plan for educational informatization. This is supported by a bottom-up ecosystem of universities, research centers and industry partners. In Vietnam, research growth has been driven by the institutional imperative to build teacher capacity under the 2018 competency-based general education curriculum, prompting systematic investment in pre-service and in-service STEAM development (Thuy et al., 2021). In contrast, Africa, Latin America, the Middle East and Central Asia remain largely absent from the reviewed literature. This reflects not merely limited STEAM activity, but deeper structural constraints including competing national priorities (food security, healthcare, basic infrastructure) and chronically low research and development investment. For example, sub-Saharan Africa allocates only 0.51% of GDP versus a global average of 1.79% (Sarpong & Adelekan, 2023). As such, this adds to the compounding effect of Global North dominance in research production and English-language publication restrictions (Mudaly & Chirikure, 2023).

DISCUSSION

This study systematically reviewed the literature on STEM/STEAM teacher competencies by examining five key dimensions: main competencies, sub-dimensions, competency models, competency frameworks and the geographic distribution of research. Teacher competencies directly shape instructional practices, pedagogical decision-making, and professional development (Selvi, 2010). The findings are interpreted through constructivist learning theory, which views knowledge as actively constructed through experience, social interaction and reflection (Vygotsky, 1978). From this perspective, STEAM teacher competency is understood not as a fixed set of skills, but as a dynamic and context-dependent professional capability continuously reconstructed through teaching practice and collaborative reflection.

This review identified a recurring three-dimensional structure in STEM teacher competency research, comprising cognitive, pedagogical and affective-motivational dimensions. Across diverse national contexts, these dimensions consistently include content and interdisciplinary knowledge, teaching and assessment skills and professional attitudes such as reflection and collaboration. This structure extends Shulman's (1987) distinction between content knowledge and pedagogical content knowledge by incorporating affective dimensions associated with constructivist perspectives on teacher identity. Recent studies further emphasize collaboration and professional engagement as core competencies rather than supplementary elements (Caner & Ogan-Bekiroglu, 2025; Margot & Kettler, 2019; Ogodo, 2024). In contrast,, STEAM competency frameworks appear more complex and multidimensional, reflecting the additional demands of arts integration, creative pedagogy and constructivist learning environments (Henriksen et al., 2019; Kim & Kim, 2016; Spyropoulou & Kameas, 2023).

According to the reviewed studies, project-based and inquiry-based learning consistently emerged as central approaches to STEAM competency development (Caner & Ogan-Bekiroglu, 2025; Chamrat & Suyamoon, 2024; Oanh, 2024). Their prominence suggests that authentic, interdisciplinary problem-solving simultaneously as an effective student pedagogy and a form of experiential professional learning for educators. Evidence indicates that STEAM professional development programs involving active project participation are more effective than lecture-based or discipline-isolated training in fostering integrated competencies (Margot & Kettler, 2019). Moreover, the emphasis on collaboration and professional engagement in recent competency frameworks highlights communities of practice as an important model for sustainable teacher development (Hidayat et al., 2018; Qudratuddarsi et al., 2022; Spyropoulou & Kameas, 2023). For example, South Korea's STEAM research and teaching groups, supported by KOFAC funding, demonstrate how institutionalized teacher networks can effectively sustain long-term collaborative professional learning (Kang, 2019).

This review shows that arts-related competencies in STEAM frameworks are often broadly labelled as "arts literacy," without consistent differentiation of their internal dimensions. In this study, they are separated into three categories: discipline-specific artistic knowledge, creativity and divergent thinking skills, and arts-integrated pedagogical practice. Although related to the "A" in STEAM, these constructs differ sharply in theoretical origins and instructional functions. Recent work warns that combining them can create conceptual ambiguity in competency frameworks (Henriksen et al., 2019). Creativity competency refers to domain-general abilities such as fluency, flexibility and originality (Shi et al., 2020). This is supported through arts-based activities that enhance divergent thinking and visualization (Sheridan et al., 2022). Aesthetic and design thinking provides a structured problem-solving process involving empathy, ideation and iteration (Bedewy & Lavicza, 2023; Henriksen et al., 2019). Arts pedagogical practice focuses specifically on using artistic media and processes to teach STEM concepts. Clear differentiation of these constructs is essential for developing effective STEAM teacher education programs.

Therefore, this study intentionally builds on the framework proposed by Spyropoulou and Kameas (2023) to construct an optimized, revised STEAM teacher competency framework (**Appendix F**). Although the STEAMComp Edu framework is comprehensive, its arts-related components remain underdeveloped, with creativity embedded as "transferable skills" rather than as a distinct domain, and with arts pedagogy, aesthetic literacy, and design thinking not clearly operationalized. First, within educator role 1, under 1.2 STEAM foundations, this study proposes adding foundational aesthetic literacy across visual arts, music, drama, design and architecture. This will directly address the current superficial use of visual arts due to limited teacher preparation. Creative thinking should also be explicitly recognized as a teachable core competency, requiring cognitive flexibility and instructional improvisation (Sawyer, 2019), and included in educator role 5, while "identifying and assessing students' creative products" is added to 1.4 feedback and assessment. Second, design thinking is integrated into 2.1 educational design and 1.4 assessment, emphasizing its five-stage cycle for problem-solving, collaboration and iterative refinement. Finally, as arts integration can be challenging for non-arts educators (Perignat & Katz-Buonincontro, 2019), formal collaboration between arts and STEAM teachers is added to educator role 3 (3.2 stakeholder coordination), including the assessment of interdisciplinary learning outcomes.

In terms of geographic distribution, research on STEM/STEAM teacher competencies is highly concentrated in Asia. This pattern differs sharply from a review on STEAM sustainability in teacher education, where Spain and the United States were more prominent (Ariza & Olatunde-Aiyedun, 2024). Another review on scientific design thinking and integrated STEM/STEAM found that the United States, China and Australia dominate publication output and citations (Saseendran & Thomas, 2025). These differences suggest that while Western countries lead in overall STEAM research, studies specifically focused on teacher competencies and frameworks remain limited. Regional variations are shaped by social, cultural and economic factors.

Developed countries emphasize interdisciplinary integration and equity, while developing countries tend to focus more on implementation (Zhan et al., 2022). This imbalance highlights an urgent need for context-sensitive competency research and locally adapted frameworks, specifically in underrepresented regions such as MENA (Ogodo, 2024; Putra et al., 2024; Spyropoulou & Kameas, 2023).

CONCLUSIONS AND IMPLICATIONS

This systematic review analyzed 28 studies on STEM and STEAM teacher competencies published between 2016 and 2025 across WoS, Scopus, Google Scholar, and ERIC. The findings indicate that most existing studies focus on defining competency components and adapting frameworks to national educational contexts. Three major gaps emerged: the underrepresentation of arts-related competencies, the limited availability of validated competency models, and the geographical concentration of research in East and Southeast Asia. The review identified a stable three-dimensional competency structure consisting of cognitive, pedagogical and affective-motivational dimensions. It extended previous research by distinguishing arts competency into arts knowledge, creative thinking skills and arts-integrated teaching practice. Methodologically, the review applied the PRISMA 2020 framework, MMAT quality appraisal, inter-rater reliability testing and thematic synthesis. By addressing publication, selection and language bias, the study provides a transparent, rigorous and reproducible foundation for future STEAM competency research across diverse educational systems.

The findings of this review have vital implications for STEAM teacher education and global policy development. STEM and STEAM frameworks consistently emphasize subject knowledge, student-centered pedagogy and technology integration as core competencies that should guide teacher preparation curricula. However, current programs insufficiently address affective-motivational and arts-related competencies. Evidence suggests that teacher self-efficacy and professional identity develop through sustained, community-based professional learning rather than short-term workshops. Programs should therefore include reflective practice, collaborative inquiry and formal professional learning communities. Arts-related competencies require dedicated curriculum modules and co-teaching between arts and STEM educators. Finally, policymakers should support locally grounded competency research and internationally collaborative, context-sensitive framework development initiatives.

This review highlights an urgent need to develop STEAM teacher competency frameworks which are empirically validated, theoretically integrated and context sensitive. A common tendency in the existing literature is to construct competency frameworks through expert consultation and curriculum analysis, without further empirical validation using teacher surveys, classroom observations or longitudinal tracking of professional development outcomes. Therefore, future framework development must adopt a mixed-methods validation design. This should combine quantitative confirmatory factor analysis with qualitative perspectives from teachers and educators. Such an approach would ensure that competency models are both statistically robust and grounded in the real practices of STEAM educators. The review also finds that competency frameworks were mainly developed in resource-rich and policy-driven STEAM ecosystems.

Limitation and Recommendations

This study has several limitations which may have influenced data collection and interpretation. First, it included only English-language publications, which may have excluded relevant studies published in other languages, particularly those from China, South Korea and Vietnam, where national competency frameworks are often reported in local languages. This limits both geographical coverage and conceptual completeness. Second, the review relied on four databases. Though Google Scholar was included to capture grey literature, its inconsistent indexing may affect reproducibility. The exclusion of books, book chapters, and monographs may also omit important theoretical contributions. Third, there is notable conceptual heterogeneity across the 28 included studies, with varying definitions of "competency," "framework," and "model," alongside diverse methodological approaches, which limits direct comparability. Finally, restricting the review to studies published between 2016 and 2025 captures only a specific development phase of STEAM competency research and may overlook earlier or emerging contributions.

Drawing on this systematic review, future research and policy should focus on developing and empirically validating holistic, context-sensitive STEM/STEAM teacher competency models which seamlessly integrate subject knowledge, pedagogical expertise, technological proficiency and artistic dimensions. Teacher education and professional development programs should move beyond fragmented competency lists toward unified frameworks that support integrated instructional design, interdisciplinary assessment and sustained collaboration with community stakeholders. Greater attention is needed for arts integration, cross-disciplinary knowledge application and technology-enhanced pedagogy, as these areas remain underexplored and less empirically validated in the literature. In addition, targeted professional development initiatives should strengthen teachers' capacity to design, implement and evaluate integrated STEM/STEAM learning experiences, specifically in pre-service education. Finally, future research should expand empirical studies in underrepresented regions such as Africa and the Middle East, to improve geographic balance and support the development of culturally responsive, globally relevant competency frameworks for STEM/STEAM education.

Author contributions: CJ: conceptualization, data curation, writing – original draft, writing – review & editing; **RH:** data curation, writing – original draft, writing – review & editing; **MZBHZ:** writing – original draft, writing – review & editing. All authors agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: This study is a systematic literature review based exclusively on publicly available secondary data. It did not involve human participants, animals, or the collection of primary data requiring ethical review. Therefore, ethical approval and informed consent w.

AI statement: This article uses generative AI tools to check for coherency, grammar, and overall readability, ensuring the content is clear and well-structured.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Alcaraz-Dominguez, S., & Molas-Castells, N. (2024). STEAME projects in basic education: Validating a competence framework for educators. *Journal of New Approaches in Educational Research, 13*, Article 20. https://doi.org/10.1007/s44322-024-00019-4

Ariza, A. J., & Olatunde-Aiyedun, T. G. (2024). A systematic literature review on STEAM pre- and in-service teacher education for sustainability: Are teachers ready? *Eurasia Journal of Mathematics, Science and Technology Education, 20*(9), Article em2498. https://doi.org/10.29333/ejmste/14982

Başaran, M., & Vural, Ö. F. (2025). Perception of teachers towards STEAM and inquiry-based teaching after STEAM activities training. *Sage Open, 15*(4). https://doi.org/10.1177/21582440251388688

Bedewy, S. E., & Lavicza, Z. (2023). STEAM + X – Extending the transdisciplinary of STEAM-based educational approaches: A theoretical contribution. *Thinking Skills and Creativity, 48*, Article 101299. https://doi.org/10.1016/j.tsc.2023.101299

Boice, K. L., Jackson, J. R., Alemdar, M., Rao, A. E., Grossman, S., & Usselman, M. (2021). Supporting teachers on their STEAM journey: A collaborative STEAM teacher training program. *Education Sciences, 11*(3), Article 105. https://doi.org/10.3390/educsci11030105

Bushey, L. J. (2024). Global competency integration in STEAM fields in higher education. *Journal of Research in Science, Mathematics and Technology Education, 7*(SI), 85-115. https://doi.org/10.31756/jrsmte.315si

Caner, F., & Ogan-Bekiroglu, F. (2025). Determination of integrated STEM teacher competencies: A modified Delphi method. *European Journal of STEM Education, 10*(1), Article 06. https://doi.org/10.20897/ejsteme/16497

Chamrat, S., & Suyamoon, P. (2024). The development of teacher interns' competencies of science instructional design and implementation using STEM activity based on DIY, Tinker and maker frameworks. *Journal of Technology and Science Education, 14*(3), 990-1010. https://doi.org/10.3926/jotse.2225

Deák, C., & Kumar, B. (2024). A systematic review of STEAM education's role in nurturing digital competencies for sustainable innovations. *Education Sciences, 14*(3), Article 226. https://doi.org/10.3390/educsci14030226

Diego-Mantecon, J.-M., Prodromou, T., Lavicza, Z., Blanco, T. F., & Ortiz-Laso, Z. (2021). An attempt to evaluate STEAM project-based instruction from a school mathematics perspective. *ZDM Mathematics Education, 53*, 1137-1148. https://doi.org/10.1007/s11858-021-01303-9

El Nagdi, M., Leammukda, F., & Roehrig, G. (2018). Developing identities of STEM teachers at emerging STEM schools. *International Journal of STEM Education, 5*, Article 36. https://doi.org/10.1186/s40594-018-0136-1

ElSayary, A., Zein, R., & San Antonio, L. (2022). Using interactive technology to develop preservice teachers' STEAM competencies in early childhood education program. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(2), Article em2079. https://doi.org/10.29333/ejmste/11649

Ergül, N. R. (2021). Investigation of STEM competencies of teacher candidates. *European Journal of Physics Education, 12*(1), 38-55.

Galanti, T. M., & Holincheck, N. (2022). Beyond content and curriculum in elementary classrooms: Conceptualizing the cultivation of integrated STEM teacher identity. *International Journal of STEM Education, 9*, Article 43. https://doi.org/10.1186/s40594-022-00358-8

Hendriyanto, A., Priatna, N., Juandi, D., Dahlan, J. A., Hidayat, R., Sahara, S., & Muhaimin, L. H. (2023). Learning mathematics using an ethnomathematics approach: A systematic literature review. *Journal of Higher Education Theory & Practice, 23*(7). https://doi.org/10.33423/jhetp.v23i7.6012

Hendriyanto, A., Suryadi, D., Juandi, D., Dahlan, J. A., Hidayat, R., Wardat, Y., & Muhaimin, L. H. (2024). The didactic phenomenon: Deciphering students' learning obstacles in set theory. *Journal on Mathematics Education, 15*(2), 517-544. https://doi.org/10.22342/jme.v15i2.pp517-544

Henriksen, D., Mehta, R., & Mehta, S. (2019). Design thinking gives STEAM to teaching: A framework that breaks disciplinary boundaries. *STEAM Education, 5*(6), 57-78. https://doi.org/10.1007/978-3-030-04003-1_4

Herro, D., Quigley, C., & Cian, H. (2019). The challenges of STEAM instruction: Lessons from the field. *Action in Teacher Education, 41*(2), 172-190. https://doi.org/10.1080/01626620.2018.1551159

Heung, I., Su, J., & Wegerif, R. (2024). STEAM in practice and research in primary schools: A systematic literature review. *Research in Science & Technological Education, 43*(4), 1065-1089. https://doi.org/10.1080/02635143.2024.2440424

Hidayat, R., & Wardat, Y. (2023). A systematic review of augmented reality in science, technology, engineering and mathematics education. *Education and Information Technologies, 29*, 9257-9282. https://doi.org/10.1007/s10639-023-12157-x

Hidayat, R., Adnan, M., & Abdullah, M. F. N. L. (2022). A systematic literature review of measurement of mathematical modeling in mathematics education context. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(5), Article em2108. https://doi.org/10.29333/ejmste/12007

Hidayat, R., Nugroho, I., Zainuddin, Z., & Ingai, T. A. (2024). A systematic review of analytical thinking skills in STEM education settings. *Information and Learning Sciences, 125*(7-8), 565-586. https://doi.org/10.1108/ils-06-2023-0070

Hidayat, R., Syed Zamri, S. N. A., & Zulnaidi, H. (2018). Does mastery of goal components mediate the relationship between metacognition and mathematical modelling competency? *Educational Sciences: Theory and Practice, 18*(3), 579-604. https://doi.org/10.12738/estp.2018.3.0108

Holincheck, N., & Galanti, T. M. (2023). Applying a model of integrated STEM teacher identity to understand change in elementary teachers' STEM self-efficacy and career awareness. *School Science and Mathematics, 123*(6), 234-248. https://doi.org/10.1111/ssm.12610

Hong, Q. N., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M.-P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M.-C., Vedel, I., & Pluye, P. (2018). The mixed methods appraisal tool (MMAT) version 2018 for information professionals and researchers. *Education for Information, 34*(4), 285-291. https://doi.org/10.3233/EFI-180221

Hong, Q. N., Pluye, P., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M.-P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M.-C., & Vedel, I. (2019). Improving the content validity of the mixed methods appraisal tool: A modified e-Delphi study. *Journal of Clinical Epidemiology, 111*, 49-59.E1. https://doi.org/10.1016/j.jclinepi.2019.03.008

Hu, W., & Guo, X. (2021). Toward the development of key competencies: A conceptual framework for the STEM curriculum design and a case study. *Frontiers in Education, 6*(1). https://doi.org/10.3389/feduc.2021.684265

Huang, B., Jong, M. S.-Y., Tu, Y.-F., Hwang, G.-J., Chai, C. S., & Yi-Chao Jiang, M. (2022). Trends and exemplary practices of STEM teacher professional development programs in K-12 contexts: A systematic review of empirical studies. *Computers & Education, 189*, Article 104577. https://doi.org/10.1016/j.compedu.2022.104577

Huang, X., Erduran, S., Zhang, P., Luo, K., & Li, C. (2022). Enhancing teachers' STEM understanding through observation, discussion and reflection. *Journal of Education for Teaching, 48*(5), 576-591. https://doi.org/10.1080/02607476.2021.2006571

Ilić, I. S., Peixoto, F., Boričić, M. D., Videnović, M., Castro Silva, J., Ferreira, N., & Monteiro, V. (2025). Construction of a scale measuring primary teachers' self-efficacy to teach STEAM: The STEAM-TSES. *Frontiers in Education, 9*(1). https://doi.org/10.3389/feduc.2024.1519327

Jiayuan, M., & Hidayat, R. (2025). The mediating role of emotional intelligence and emotional resistance between interpersonal mindfulness and teacher-student interaction among teachers in China. *Current Psychology, 44*(4), 2805-2819. https://doi.org/10.1007/s12144-025-07393-y

Kang, N.-H. (2019). A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea. *Asia-Pacific Science Education, 5*, Article 6. https://doi.org/10.1186/s41029-019-0034-y

Karampelas, K. (2023). Examining the relationship between TPACK and STEAM through a bibliometric study. *European Journal of Science and Mathematics Education, 11*(3), 488-498. https://doi.org/10.30935/scimath/12981

Karampelas, K. (2026). AI meets STEAM: A global bibliometric analysis of interdisciplinary education and innovation. *Eurasian Journal of Science and Environmental Education, 6*(1), 51-60. https://doi.org/10.30935/ejsee/18441

Kim, B. H, & Kim, J. (2016). Development and validation of evaluation indicators for teaching competency in STEAM Education in Korea. *Eurasia Journal of Mathematics, Science and Technology Education, 12*(7), 1909-1924. https://doi.org/10.12973/eurasia.2016.1537a

Le, H. T. T., Pham, C. K., Le, N. C., Nguyen, N. T., Nguyen, N. T. L., Khuat, H. T. T., Nguyen, D. V., Vu, T. T., & Nguyen, T. T. T. (2025). STEM teaching competency of general education teachers: Concept, definition, and theoretical framework. *European Journal of STEM Education, 10*(1), Article 38. https://doi.org/10.20897/ejsteme/17654

Leavy, A., Dick, L. K., Meletiou-Mavrotheris, M., Efi Paparistodemou, & Stylianou, E. (2023). The prevalence and use of emerging technologies in STEAM education: A systematic review of the literature. *Journal of Computer Assisted Learning, 39*(4), 1061-1082. https://doi.org/10.1111/jcal.12806

Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2020). Research and trends in STEM education: A systematic review of journal publications. *International Journal of STEM Education, 7*, Article 11. https://doi.org/10.1186/s40594-020-00207-6

Machado, L. R., Bilessimo, S. M. S., Maciel, M. B., Silva, J. B. da, & Silva, I. N. da. (2022). Competencies for STEAM areas: A focus on teacher. *International Journal of Advanced Engineering Research and Science, 9*(8), 165-180. https://doi.org/10.22161/ijaers.98.20

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education, 6*, Article 2. https://doi.org/10.1186/s40594-018-0151-2

Marlina, R., Suwono, H., Ibrohim, I., Yuenyong, C., Hamdani, H., & Pamungkas, R. (2025). CRTP: Learning model for integrating STEM competencies in pre-service biology teachers. *Journal of Education and Learning, 19*(3), 1466-1473. https://doi.org/10.11591/edulearn.v19i3.21818

McClelland, D. C. (1973). Testing for competence rather than for "intelligence." *American Psychologist, 28*(1), 1-14. https://doi.org/10.1037/h0034092

Mei, A., Marsigit, Purwastuti, L. A., Hidayat, R., & Ayub, A. F. M. (2025). Problem-solving learning model based on ethnomathematics to improve student's creative thinking in elementary school. *Malaysian Journal of Mathematical Sciences, 19*(1), 289-309. https://doi.org/10.47836/mjms.19.1.15

Mir, A. H., Alam, M. N., & Modi, A. (2025). Constructivist learning theory: A framework for student-centered instruction in the 21st century classroom. *International Journal of Educational Review, Law and Social Sciences, 5*(4), 1273-1283.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017-1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Mohd Saad, M. R., Mamat, S., Hidayat, R., & Othman, A. J. (2023). Integrating technology-based instruction and mathematical modelling for STEAM-based language learning: A sociocultural and self-determination theory perspective. *International Journal of Interactive Mobile Technologies, 17*(14), 55-80. https://doi.org/10.3991/ijim.v17i14.39477

Morales, M. P. E., Anito, J. C., Avilla, R. A., Abulon, E. L. R., & Palisoc, C. P. (2019). Proficiency indicators for Philippine STEAM (science, technology, engineering, agri/fisheries, mathematics) educators. *Philippine Journal of Science, 148*(2), 263-275.

Morales, M. P. E., Mercado, F., Avilla, R., Palisoc, C., Palomar, B., Sarmiento, C., Butron, B., & Ayuste, T. O. (2020). Teacher professional development program (TPDP) for teacher quality in STEAM education. *International Journal of Research in Education and Science, 7*(1), 188-206. https://doi.org/10.46328/ijres.1439

Morze, N., & Strutynska, O. (2021). STEAM competence for teachers: Features of model development. In *Proceedings of the E-Learning in the Time of COVID-19* (pp. 187-198). https://doi.org/10.34916/el.2021.13.16

Mudaly, R., & Chirikure, T. (2023). STEM education in the Global North and Global South: Competition, conformity, and convenient collaborations. *Frontiers in Education, 8*(1). https://doi.org/10.3389/feduc.2023.1144399

Nurhuda, A., Al Khoiron, M. F., Azami, Y. S. I., & Ni'mah, S. J. (2023). Constructivism learning theory in education: Characteristics, steps and learning models. *Research in Education and Rehabilitation, 6*(2), 234-242. https://doi.org/10.51558/2744-1555.2023.6.2.234

Oanh, D. T. K. (2024). Integrated STEM education competence framework for university lecturers. *European Journal of Educational Research, 14*(1), 135-150. https://doi.org/10.12973/eu-jer.14.1.135

Ogodo, J. A. (2024). Culturally responsive pedagogical knowledge: An integrative teacher knowledge base for diversified STEM classrooms. *Education Sciences, 14*(2), 124-124. https://doi.org/10.3390/educsci14020124

Ortiz-Laso, Z., Diego-Mantecón, J.-M., Lavicza, Z., & Blanco, T. F. (2023). Teacher growth in exploiting mathematics competencies through STEAM projects. *ZDM Mathematics Education, 55*, 1283-1297. https://doi.org/10.1007/s11858-023-01528-w

Ortiz-Revilla, J., Ruiz-Martín, Á., & Greca, I. M. (2023). Conceptions and attitudes of pre-school and primary school teachers towards STEAM education in Spain. *Education Sciences, 13*(4), Article 377. https://doi.org/10.3390/educsci13040377

Park, W., & Cho, H. (2022). The interaction of history and STEM learning goals in teacher-developed curriculum materials: Opportunities and challenges for STEAM education. *Asia Pacific Education Review, 23*, 457-474. https://doi.org/10.1007/s12564-022-09741-0

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity, 31*, 31-43. https://doi.org/10.1016/j.tsc.2018.10.002

Putra, Z. H., Ramiati, Zufriady, Hidayat, R., Jismulatif, Hermita, N., & Sulistiyo, U. (2024). Development of computational thinking tasks based on Riau Malay culture: A study of fifth-grade public school students in Pekanbaru, Indonesia. *Education 3-13, 52*(8), 1387-1397. https://doi.org/10.1080/03004279.2022.2150063

Qudratuddarsi, H., Hidayat, R., Shah, R. L. Z. b. R. M., Nasir, N., Imami, M. K. W., & Nor, R. b. M. (2022). Rasch validation of instrument measuring gen-Z science, technology, engineering, and mathematics (STEM) application in teaching during the pandemic. *International Journal of Learning, Teaching and Educational Research, 21*(6), 104-121. https://doi.org/10.26803/ijlter.21.6.7

Radvila, V., Bredelytė, A., & Lekutienė, K. (2025). Empowering STEAM educators through AI: A conceptual framework for adaptive, inclusive professional development. *Social Welfare: Interdisciplinary Approach, 15*, 160-174. https://doi.org/10.15388/sw.2025.15.9

Rüütmann, T. (2023). Engineering pedagogy and engineering educators' competency model for effective teaching and learning STEAM. *Problems of Education in the 21st Century, 81*(4), 531-546. https://doi.org/10.33225/pec/23.81.531

Sarpong, J., & Adelekan, T. (2023). Globalisation and education equity: The impact of neoliberalism on Universities' mission. *Policy Futures in Education, 22*(6), 1114-1129. https://doi.org/10.1177/14782103231184657

Saseendran, A., & Thomas, M. V. (2025). Design thinking in science and integrated STEM/STEAM education: Trends, challenges, and future directions from a systematic review. *STEM Education, 5*(6), 1058-1101. https://doi.org/10.3934/steme.2025046

Sawyer, K. (2019). *The creative classroom: Innovative teaching for 21st-century learners*. Teachers College Press.

Selvi, K. (2010). Teachers' competencies. *Cultura International Journal of Philosophy of Culture and Axiology, 7*(1), 167-175. https://doi.org/10.5840/cultura20107133

Sheridan, K. M., Veenema, S. A., Winner, E., & Hetland, L. (2022). *Studio thinking 3: The real benefits of visual arts education*. Teachers College Press.

Shi, L., Beaty, R. E., Chen, Q., Sun, J., Wei, D., Yang, W., & Qiu, J. (2020). Brain entropy is associated with divergent thinking. *Cerebral Cortex, 30*(2), 708-717. https://doi.org/10.1093/cercor/bhz120

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

So, H.-J., Ryoo, D., Park, H., & Choi, H. (2019). What constitutes Korean pre-service teachers' competency in STEAM education: Examining the multi-functional structure. *The Asia-Pacific Education Researcher, 28*(1), 47-61. https://doi.org/10.1007/s40299-018-0410-5

Song, M. (2017). Teaching integrated STEM in Korea: Structure of teacher competence. *International Journal on Math, Science and Technology Education, 2*(4), 61-72.

Song, M. (2019). Integrated STEM teaching competencies and performances as perceived by secondary teachers in South Korea. *International Journal of Comparative Education and Development, 22*(2), 131-146. https://doi.org/10.1108/ijced-02-2019-0016

Spyropoulou, N. D., & Kameas, A. D. (2021). Educators' competences for STE (A) M education: A case study in Greece. In *Proceedings of Panhellenic and International Conference on STE(A)M Educators and Education* (pp. 504-514).

Spyropoulou, N. D., & Kameas, A. D. (2023). Augmenting the impact of STEAM education by developing a competence framework for STEAM educators for effective teaching and learning. *Education Sciences, 14*(1), Article 25. https://doi.org/10.3390/educsci14010025

Spyropoulou, N. D., Ioannou, M., & Kameas, A. D. (2025a). Impact framework for transforming STEAM education: A multi-level approach to evidence-based reform. *Education Sciences, 15*(11), 1552-1552. https://doi.org/10.3390/educsci15111552

Spyropoulou, N. D., Mathiopoulos, K., & Kameas, A. D. (2025b). *"We believe in STEAM education, but we need support"*: In-service teachers' voices on the realities of STEAM implementation. *Education Sciences, 15*(10), 1300-1300. https://doi.org/10.3390/educsci15101300

Tahiru, F. (2021). AI in education: A systematic literature review. *Journal of Cases on Information Technology, 23*(1), 1-20. https://doi.org/10.4018/jcit.2021010101

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Medical Research Methodology, 8*, Article 45. https://doi.org/10.1186/1471-2288-8-45

Thuy, T., Oanh, D. T., Binh, P. T., Ninh, T. T., The, M., Dung, L. V., & Duc, N. M. (2021). Practical investigating of STEM teaching competence of pre-service chemistry teachers in Vietnam. *Journal of Physics. Conference Series, 1835*, Article 012069. https://doi.org/10.1088/1742-6596/1835/1/012069

Utami, A., Sujarwo, S., Fauziyah, P. Y., Mustadi, A., Hidayat, R., & Rofiki, I. (2024). Bibliometric analysis of research developments on differentiated instruction. *European Journal of Educational Research, 13*(3), 1421-1439. https://doi.org/10.12973/eu-jer.13.3.1421

Valentová, M., & Brečka, P. (2025). Kindergarten teachers' readiness for STEM education: An analysis of technical competencies. *TEM Journal, 14*(3), 2483-2490. https://doi.org/10.18421/TEM143-52

Vaz-Rebelo, P., Santos, V., & Bidarra, G. (2025). Exploring poly-universe in teacher education: Examples from STEAM curricular areas and competences developed. *Open Education Studies, 7*(1), Article 20250085. https://doi.org/10.1515/edu-2025-0085

Vogelsang, C., Scholl, D., Meier, J., & Küth, S. (2025). Thoughts are free—Differences between unstructured and structured reflections of teachers with different levels of expertise. *Education Sciences, 15*(7), Article 820. https://doi.org/10.3390/educsci15070820

Vygotsky, L. (1978). *Mind in society*. Harvard University Press

Wiegand, S., & Ferri, R. B. (2023). Promoting pre-service teachers' professionalism in steam education and education for sustainable development through mathematical modelling activities. *ZDM Mathematics Education, 55*, 1269-1282. https://doi.org/10.1007/s11858-023-01500-8

Xenakis, A. (2025). AI-based models for assessing STEAM engineering literacy for university students: The case of digital systems for precision agriculture. *Hellenic Journal of STEM Education, 4*(1), 1-9. https://doi.org/10.51724/hjstemed.v4i1.37

Zhan, Z., Shen, W., Xu, Z., Niu, S., & You, G. (2022). A bibliometric analysis of the global landscape on STEM education (2004-2021): Towards global distribution, subject integration, and research trends. *Asia Pacific Journal of Innovation and Entrepreneurship, 16*(2), 171-203. https://doi.org/10.1108/apjie-08-2022-0090

Zhuofan, H., Hidayat, R., & Ayub, A. F. M. (2024). The mediating effect of engagement in the relationship between self-efficacy and perceived learning in the online mathematics environment among Chinese students. *Discover Sustainability, 5*, Article 469. https://doi.org/10.1007/s43621-024-00586-8

APPENDIX A

Table A1. Teacher STEM/STEAM main competencies

No	Author	Teacher STEAM main competencies
10	ElSayary et al. (2022)	Critical thinking, collaboration, communication, creativity & innovation, self-direction, connection, interactive technology
13	Machado et al. (2022)	Using basic computer resources, using mobile devices, using basic Internet resources, using productivity tools, research with digital technologies, using the digital whiteboard, developing and applying a plan, developing and applying blended learning, develop and apply distance education, developing and applying the maker culture, using games
16	Hu and Guo (2021)	Scientific concepts, scientific thinking, inquiry practice, information literacy competencies, attitudes and accountability
19	Vaz-Rebelo et al. (2025)	Sciences and mathematics, classification, sciences and mathematics, crystallography, mathematics and sciences, symmetries, mathematics and history, Sierpinski triangle, history and philosophy, working with logic and rules, humanities, storytelling, mathematics and sports, maze
22	Chamrat and Suyamoon (2024)	Well-designed lesson, cognitive demand variation (learning progression), student-centered approach, reflective opportunities for students, project-based learning assignments, TPACK reflection in lessons
26	Le et al. (2025)	Content knowledge, pedagogical skills, technology use skills

APPENDIX B

Table B1. Teacher STEM/STEAM other competencies

No	Author	Focus	Competencies
5	Ortiz-Laso et al. (2023)	M (STEAM)	Modelling, computational thinking, intra-mathematical connections, mathematical representations, collaborative work and positive identity
6	Morales et al. (2019)	PPST (STEAM)	Content knowledge and pedagogy, learning environment, diversity of learners, curriculum and planning, assessment and reporting, community linkages and professional engagement, personal growth and professional development
8	Bushey (2024)	GC (STEAM)	GC initiatives built into course objectives, GC initiatives present in resources and lesson topics, GC strategies incorporated into class activities and teaching interactions
14	Wiegand and Rita (2023)	M (STEAM)	Competencies for modelling: theoretical, task, instructional, diagnostic,
17	Holincheck and Galanti (2023)	STEM teacher identity	Motivation, self-image, self-efficacy, task perception, teaching interest
21	Rüütmann (2023)	E (STEAM)	STEAM professional competencies, pedagogical, social, psychological and ethical competencies, STEAM didactical skills and subject expertise, evaluative competencies, organizational/management competencies, communicative and teamwork competencies, reflective and developmental competencies
24	Marlina et al. (2025)	biology-STEM	Reflection, collaboration, integration of interdependent STEM disciplines, skills related to STEM disciplines, integrative STEM teaching and learning
27	Valentová and Brečka (2025)	T (STEM)	Inquiry and material exploration competencies, technological representation and interpretation competencies, engineering design and problem-solving competencies, technical and practical skills competencies, engineering principles and career awareness competencies

APPENDIX C

Table C1. Teacher STEM/STEAM main competencies – Sub-dimension

Competency dimension	STEM			STEAM		
	Song (2017, 2019), Caner Ogan-Bekiroglu (2025)	Ergül (2021), B. Huang et al. (2022)	Sub-dimensions (STEM)	Kim and Kim (2016), Spyropoulou and Kameas (2021)	So et al. (2018), Morze and Strutynska (2021)	Sub-dimensions (STEAM)
1. Disciplinary & interdisciplinary knowledge	Cognitive characteristics: STEM content knowledge. Interdisciplinary connection knowledge. STEM curriculum knowledge. Creativity based on inter-disciplinary knowledge	Knowledge: STEM Knowledge. Integration knowledge. Production & processing. Computers & electronics	Ability to link/reorganize curriculum across STEM subjects. Scientific understanding of real-world issues. Recognition of correct concept of integrated STEM	Understanding of subjects: Understand & reorganize STEAM-related curriculum. Connect and integrate subject content. Select key concepts across STEAM subjects	STEAM knowledge: Mathematics, technology, engineering. Natural sciences. Design planning & modeling. Foreign language & basics of design	Interdisciplinary content mastery. Cross-subject curriculum reorganization. Integration of STEAM subject concepts
2. Pedagogical & instructional skills	Instructional skills: PBL/project-based curriculum. Student-centered activity. Teacher as learning assistant. Alternative assessment. Instruction using IT/ICT	Skills: Critical thinking. Active learning. Complex problem-solving. Technology design. Operations analysis	Applying PBL & team-teaching. Emphasizing student autonomy. Alternative assessment. Guiding students to apply learned knowledge	Teaching-learning methods: Suggest instructional objectives. Arouse motivation via real-life situations. Inquiry & feedback-based instruction. Cooperative learning activities	Methodical competence: STEAM curriculum development. Methods supporting higher-order thinking. Creative problem-solving methods. Understanding students' learning needs	Inquiry-based & PBL strategies. Student-centered instructional design. Formative & summative assessment. Differentiated instruction
3. Assessment competency	Alternative assessment; STEM teaching & learning assessment. Consideration of student differences	Quality control analysis. Operations monitoring	Using alternative assessments. Assessing higher-order thinking. Feedback from evaluation results	Evaluation of learners: Quantitative & qualitative evaluation. Diversity-responsive assessment. Higher-order thinking evaluation. Convergent evaluation methods	Feedback & assessment. Assessing learning outcomes. Motivating through evaluation rewards	Multi-method assessment. Process-based assessment. Feedback-driven improvement
4. Technology & digital competency	Technology literacy. Instruction using ICT & multimedia. TPACK integration	Engineering & technology knowledge. Equipment selection & maintenance. System analysis	ICT-based instruction. Technology application in STEM. Technology design skills	Use content and tools. Digital skills & digital literacy	Digital competence: Computer science knowledge. Algorithmic thinking. Digital technologies in STEAM. Data analysis & interpretation	Technology integration in teaching. Digital tool proficiency. ICT-enhanced learning design

Table C1 (Continued).

	STEM			STEAM		
Competency dimension	Song (2017, 2019), Caner Ogan-Bekiroglu (2025)	Ergül (2021), B. Huang et al. (2022)	Sub-dimensions (STEM)	Kim and Kim (2016), Spyropoulou and Kameas (2021)	So et al. (2018), Morze and Strutynska (2021)	Sub-dimensions (STEAM)
5. Affective-motivational & professional identity	Affective characteristics: Willingness & enthusiasm for integrated STEM. Open mind to cross-subject knowledge. Self-examination & continuous improvement. Belief & patience with students	Abilities: Inductive & deductive reasoning. Problem sensitivity; Perceptual speed	Communication & cooperation with teachers; Surmounting anxiety on unfamiliar knowledge. Continuous efforts for teaching quality improvement	Individual qualification Kim and Kim (2016): Belief in and dedication to STEAM education Positive attitude towards teacher cooperation. Self-diagnosis and reflection. Open acceptance of others' opinions	Soft skills Morze and Strutynska (2021): Critical & creative thinking. Communication & teamwork. Decision making. Openness to new ideas	Professional self-reflection. Collaborative attitude. Commitment to interdisciplinary practice. Growth mindset
6. Collaboration & community engagement	Collaboration with colleagues & stakeholders. Engagement in STEM learning communities	Team coordination. Operation and control	Cooperating with other subject teachers. Team-teaching arrangements	Interacting with the environment: Community building. Application of policies	Cooperation among teachers. Devising classes cooperatively	Cross-disciplinary co-teaching. Professional community participation. Policy engagement
STEM-specific dimensions						
7. STEM disciplinary ability	STEM attitude: Attitudes towards connections between STEM disciplines. STEM career interest. Effect of STEM education	STEM ability (B. Huang et al., 2022): Problem-solving ability. Scientific inquiry ability. Mathematical modelling ability. Engineering design ability. Technical application ability	Recognizing problems comprehensively. Flexible thinking beyond subject boundaries. Applying discipline-specific inquiry processes			
8. Mathematical & logical reasoning	Mathematical reasoning. Number facility. Deductive & inductive reasoning	Skills: Mathematics. Mathematical modelling. Mathematical knowledge	Mathematical problem-solving. Quantitative reasoning in STEM contexts			
STEAM-specific dimensions						
9. Arts knowledge & aesthetic literacy				Art appreciation So et al. (2018): Standalone primary competency domain (Sub-dimensions unelaborated)	Artistic connection Bedewy and Lavicza (2023): GeoGebra-based arts integration. Historical & cultural arts connections. Architectural connections	Subject-specific arts knowledge. Aesthetic perception & appreciation. Arts-STEM conceptual connections (Conceptually underdeveloped across frameworks)

Table C1 (Continued).

	STEM			STEAM		
Competency dimension	Song (2017, 2019), Caner Ogan-Bekiroglu (2025)	Ergül (2021), B. Huang et al. (2022)	Sub-dimensions (STEM)	Kim and Kim (2016), Spyropoulou and Kameas (2021)	So et al. (2018), Morze and Strutynska (2021)	Sub-dimensions (STEAM)
10. Creative competency & design thinking				Creative Convergence So et al. (2018): Information processing & utilization. Convergent thinking	Soft Skills Morze & Strutynska (2021): Creative thinking. Innovation & problem-solving STEAM attitude Kim & Kim (2016)	Divergent & convergent thinking. Creativity & innovation. Design thinking as pedagogy (No framework operationalizes design thinking as standalone domain)
11. Learning environment design				Learning environments Kim and Kim (2016): Select effective teaching media. Develop & reorganize STEAM materials. Manage time & space for STEAM activities. Handle unexpected class situations	Designing outputs Spyropoulou and Kameas (2021): Course & curriculum design. Coordinating procedures & outputs. Resource management	Physical & virtual learning space. Material development & adaptation. Classroom management for STEAM projects (more elaborated in STEAM than STEM)
12. Professional development & transferable skills				Developing & applying competences Spyropoulou and Kameas (2021): Transferable skills. Digital skills. Continuous professional development	Some other key competencies Morze and Strutynska (2021): Ability to learn. Civic & social competence. Entrepreneurship. Environmental literacy	Lifelong learning orientation. Transferable & 21st century skills. Civic & global engagmMore systematically elaborated in STEAM frameworks)

APPENDIX D

Table D1. Proposed integrated STEM education competence framework for university lecturers (Oanh, 2024)

Component competence	Original item code	Examples of item description
Having STEM literacy (SL)	SL1	Master fundamental knowledge and skills in the four disciplines: science, technology, engineering, and mathematics
Developing integrated STEM education curricula (DS)	DS1	Differentiate between STEM education programs that focus on a single discipline and those that integrate two or more disciplines
Implementing the student-centered approach in integrated STEM education (IS)	IS1	Foster a collaborative, active learning environment when organizing integrated STEM learning activities for students
Assessing integrated STEM learning outcomes (AS)	AS1	Assess students' performance in integrated STEM lessons and topics using valid, reliable tools and methods.
Demonstrate positive attitudes towards integrated STEM education (DA)	DA1	Exhibit enthusiasm and creativity when designing and delivering integrated STEM lessons and topics.

APPENDIX E

Table E1. Initial STEAM educators' competence framework perspectives, areas, and examples of competences (Spyropoulou & Kameas, 2023)

Perspectives	Areas	N	Examples of competences
1. Educator as teacher-trainer tutor/implementing the educational procedure	1.1 Pedagogy	3	1.1.2 Apply collaborative learning methods in STEAM-related activities
	1.2 Content knowledge	2	1.2.1 Understand what STEAM education approach represents and means
	1.3 Instruction	3	1.3.1 Provide guidance in STEAM-related activities
	1.4 Use content and tools	2	1.4.1 Select and use appropriate content and tools for STEAM education
	1.5 Feedback and assessment	2	1.5.1 Use assessment strategies for STEAM education
	1.6 Learner empowerment	3	1.6.1 Ensure accessibility and inclusion in STEAM-related educational procedures
2. Educator as learning designer and creator/designing and producing outputs	2.1 Course/curriculum/ activity design	3	2.1.1 Understand and develop
	2.2 Content and tools design and development	2	2.2.1 Create and modify appropriate content for STEAM education
	2.3 Learner development	2	2.3.1 Facilitate learners' STEAM competences
3. Educator as orchestrator and manager/coordinating procedures and outputs	3.1 Educational procedure management	2	3.1.1 Apply teaching organization methods for STEAM education
	3.2 Resource management	3	3.2.1 Apply educational resources management methods for STEAM education
4. Educator as community member/interacting with the environment	4.1 Community building	3	4.1.1 Engage in STEAM communities of educators
	4.2 Application of policies	2	4.2.1 Apply policies that promote STEAM education approach
5. Educator as professional/developing and applying competences	5.1 Transferable skills	7	5.1.1 Develop leadership skills
	5.2 Digital skills	2	5.2.1 Develop digital literacy skills
	5.3 Professional development	3	5.3.1 Adapt self-reflective practices for STEAM education

Note. N: Number of statements (competences)

APPENDIX F

Table F1. Initial STEAM Educators' competence framework perspectives, areas, and examples of competences, add teacher A competency, based on Spyropoulou and Kameas (2023)

Perspectives, competence areas, and competences		Item description	Changes
1. Educator as teacher-trainer-tutor/implementing the educational procedure	1.2 STEAM education foundations	1.2.2 Interdisciplinary knowledge of the arts (visual arts, music, design, and architecture fundamentals)	C
		1.2.3 The ability to make interdisciplinary connections between the arts and STEAM	N
		1.2.4 Artistic literacy from the perspective of cultural diversity	N
		1.2.5 Creative thinking and the ability to analyze problems from multiple perspectives	N
		1.2.2 Interdisciplinary knowledge of the arts (visual arts, music, design, and architecture fundamentals)	C
	1.4 Feedback and assessment	1.4.4 Ability to identify and assess students' creative products	N
		1.4.5 Student assessment based on the design process	N
		1.4.6 Interdisciplinary art and integrated learning outcomes with other disciplines	N
2. Educator as learning designer and creator/designing and creating learning opportunities	2.1 Educational design	2.1.4 Designing STEAM learning units using the five-stage design thinking framework	N
3. Educator as orchestrator and manager/coordinating procedures and outputs	3.2 Stakeholders' coordination and leadership skills	3.3.3 Facilitating interdisciplinary collaboration between art teachers and STEAM teachers	N
5. Educator as professional/developing and applying competences	5.1 Transferable skills	5.1.5 Demonstrating and fostering creative thinking in the classroom	N

Note. C: Change area & N: New additional