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Review paper

Teacher Training and Conceptual Dimensions for the Implementation of STEAM Education in Formal Educational Contexts: A Systematic Literature Review

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ABSTRACT

The knowledge society faces challenges in addressing changes in students' graduate profiles due to the rapid expansion of artificial intelligence, automation, and smart cities, which has generated the need for an educational paradigm centered on action and informed decision-making. Continuous teacher training constitutes the foundation of new educational proposals in the twenty-first century. This research was conducted through a systematic literature review following the PRISMA methodology applied to the field of education. A mixed-methods descriptive–analytical approach was adopted, supported by qualitative thematic and relational analysis aimed at identifying conceptual dimensions. A total of 96 articles were selected from the Scopus, ERIC, and Web of Science databases with the objective of analyzing the conceptual dimensions involved in the implementation of STEAM education in formal educational contexts. In conclusion, an integrated conceptual model derived from semantic network analysis inspired by Atlas.ti is consolidated. STEAM/STEM education is positioned as the structural core of the model, while teacher training is articulated as a mediating dimension that enables holistic pedagogical and didactic integration with teaching practice, in order to address challenges and leverage opportunities inherent to twenty-first-century education.

Keywords: STEAM education, STEAM, STEM, Teacher training, 21st-Century skills

Current educational trends address a wide range of aspects related to learning and skill development for both students and teachers. Therefore, it is crucial to have a teacher training program that not only promotes knowledge development but also encourages its practical application in the classroom through innovative strategies that foster active participation in the teaching-learning process. In this context, having the guidance of a teacher who supports the process in order to foster students' academic and personal growth—from trans disciplinarity to blended learning—highlights the importance of teamwork and problem-solving as essential competencies (Eronen et al., 2019). Thus, blended learning is included as an effective tool to engage students in various activities and to train them to take on leadership roles (Tupas & Linas-Laguda, 2020).

Moreover, in the knowledge society, new guidelines for curriculum design are highlighted as part of an educational reform proposal, aiming to create learning environments that foster problem-solving and adaptability across different contexts and settings (Lin, 2020). In this way, the crucial role of growth mindset pedagogy is recognized for promoting a positive attitude toward the educational process, particularly in relation to emotional regulation in student learning, while addressing their diversity, identity, and acknowledged difficulties (Lin, 2020).

In rural contexts, it is significantly evident that the characteristics, preparation, and training of teachers directly influence the success of their students (Nyatsikor et al., 2020). Therefore, it is necessary to reconsider the curriculum through a holistic approach that integrates lifelong learning while linking equity with inclusion. As a strategic proposal in higher education, it is recommended to foster the cultural identity of communities by valuing ancestral knowledge (Wu & Chen, 2021); that is, to educate with awareness and respect for the diversity of contexts, ancestral wisdom, and multilingualism—what is referred to as culturally responsive education (Knochel & Meeken, 2021) This also involves validating the cultural recognition of Indigenous communities, provided that certified teachers are in place to support this process.

In this way, contemporary education aims to empower students with 21st-century competencies such as the promotion of digital literacy, computational thinking (CT), creativity, and problem-solving. To achieve this, the integration of innovative approaches into the school curriculum through STEAM-based educational projects is proposed.

This study was conducted following a rigorous methodological approach that included the development of a conceptual mind map. Additionally, comprehensive searches were performed in the Scopus, ERIC, and Web of Science (WOS) databases.

METHOD

To ensure rigor in the selection and analysis of studies, this research is conducted as a systematic literature review, guided by the PRISMA 2020 Statement (Page et al., 2021) as applied to the field of education. A mixed-methods approach with a descriptive–analytical design is adopted, supported by qualitative thematic and relational analysis aimed at identifying conceptual dimensions for the implementation of STEAM education.

The methods used at each stage of the systematic review process are described below:

Planning

Research questions

The present study emerges from a set of guiding questions that support the formulation of RQ1, which frames the development of the research. These questions are: What challenges and opportunities of 21st-century education are identified in the scientific literature in relation to the implementation of STEAM education in formal educational contexts? and What holistic pedagogical and didactic integration approaches are described in the literature for STEAM/STEM learning in formal educational contexts?

RQ1: ¿ What conceptual dimensions emerge from the systematic literature review for the implementation of STEAM/STEM education in formal educational contexts, with teacher training positioned as a central mediating dimension?

Eligibility criteria

To select the relevant studies included in this research, inclusion and exclusion criteria were established, as detailed below (**Table 1**):

Table 1
Eligibility Criteria

Ítem	Inclusion Criteria	Exclusion Criteria
Study Variables	STEM education, STEAM education, S.T.E.M., S.T.E.A.M., teacher training, professional development, instruction, teaching practice, research, competencies.	STEAM in other areas
Typology	Articles from the Scopus, ERIC, and WOS databases to ensure research quality and rigor, peer-reviewed articles.	Book chapters, proceedings, theses, report documents, etc., non-indexed regional journals, not available in full text, not peer-reviewed through blind review.
Time Periods	2018 -2024	Publications from years other than those considered.
Language	Articles written in English and Spanish.	Languages other than English and Spanish, such as Russian, Chinese, German, etc.
Disciplines	Social Sciences	Nursing, energy, business, psychology, and agriculture.
Type of Access	Open Access	Restricted

Information sources

Table 2 below presents the most prominent and relevant journals considered in this study, all of which are indexed in the Scopus, ERIC, and WOS databases due to their broad coverage of academic literature in the field of education and their scientific recognition.

Table 2
Relevant journals where the studies were published

Journal	Q
Language Testing in Asia	Q1
Asia Pacific Education Review	Q1
Asia-Pacific Journal of Teacher Education	Q1
British Journal of Educational Technology	Q1
Science Education	Q1
Studies in Educational Evaluation	Q1
Teaching and Teacher Education	Q1
Thinking Skills and Creativity	Q1
European Journal of STEM Education	Q2
Journal of Technology and Science Education	Q2
Marketing Education Review	Q2
Perspektivy Nauki i Obrazovania	Q2
Revista Complutense de Educacion	Q2
Revista de Educación a Distancia	Q2
South African Journal of Education	Q2
Tydskrif vir Geesteswetenskappe	Q2
Moscow	Q2
LUMAT	Q3
Pedagogies	Q3
Perspectives in Education	Q3
Prisma Social	Q3
Revista Eureka	Q3
Taiwan Journal of Anthropology	Q3
Theory and Practice in Language Studies	Q3
Waikato Journal of Education	Q3
Journal of Higher Education Theory and Practice	Q4
Malaysian Online Journal of Educational Management	Q4
Pegem Egitim ve Ogretim Dergisi	Q4

Search strategy

The search strategy was designed using a combination of terms in Spanish and English, as shown in Table 3. Key terms included "STEAM," "STEM," "education," "teacher training," and "teaching practice." Filters were applied to limit the results to peer-reviewed articles published in high-impact journals.

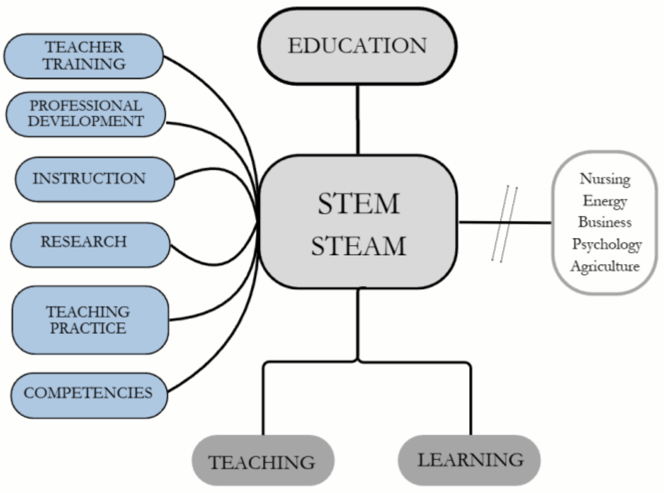
Table 3
Review Structure

L1	Education	((steam OR s.t.e.a.m. OR stem OR s.t.e.m.) AND ("formal education" OR "school education" OR "higher education"))
L2	Teacher Training	(training OR instruction OR "teaching practice" OR "teacher education" OR "teacher training" OR "teacher professional development" OR investigation OR competencies)
L3	Questions	RQ1: What conceptual dimensions emerge from the systematic literature review for the implementation of STEAM/STEM education in formal educational contexts, with teacher training positioned as a central mediating dimension?

The conceptual framework proposed in Figure 1 presents the review regarding teacher training in STEAM education. On the left side, the characteristics have been defined, while on the right side, the sciences excluded from the study are classified. In the lower part, the terms that will guide the database search are listed.

Figure 1

Conceptual mind map



Study selection

The study selection process was carried out in two phases:

• Title and Abstract Review: Studies that did not meet the inclusion criteria were excluded.

• Full-Text Review: The remaining studies were evaluated to determine their eligibility.

Data extraction

The information from the articles that meet the eligibility criteria is exported for analysis using the deductive method in order to answer the research questions posed.

Risk of bias assessment

The methodological quality guiding this research was assessed using the CASP (Critical Appraisal Skills Programmed) tool, which allowed for the identification and control of potential sources of bias associated with the methodological design, clarity of objectives, coherence between methods used and reported results, as well as transparency in interpreting findings. The studies were analyzed in detail and critically during the thematic and relational synthesis process. This contributes to minimizing unintended biases and ensuring the scientific validity of the presented results, by timely identifying methodological limitations or potential risks of bias avoiding absolute conclusions and prioritizing a well-founded conceptual synthesis.

Results synthesis

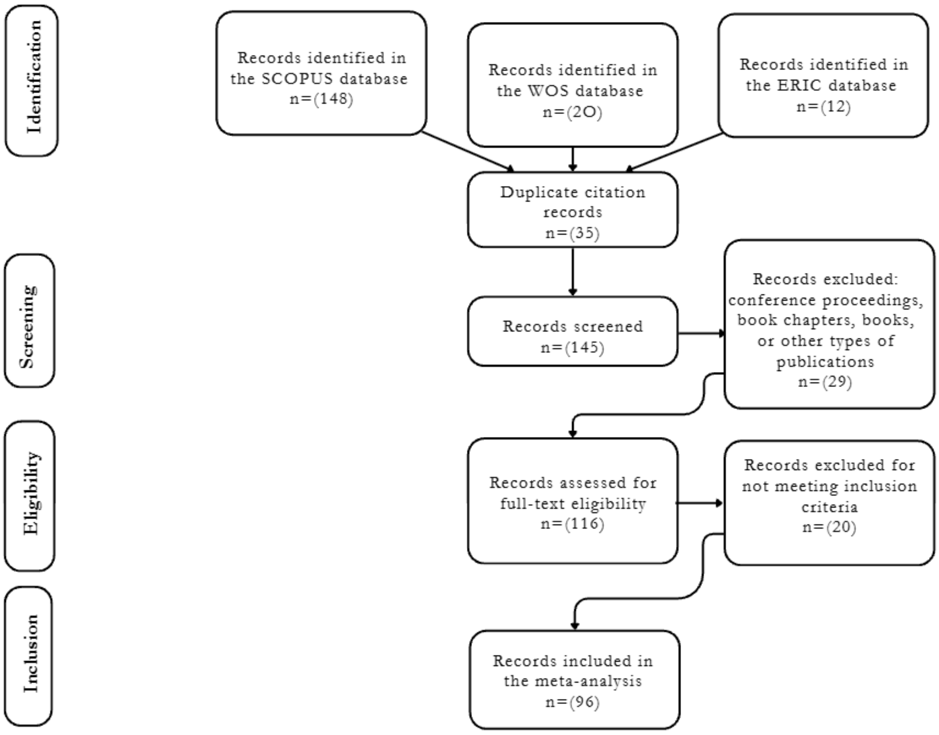
The results were synthesized using a descriptive and analytical approach through qualitative thematic and relational analysis. The findings were grouped around key themes, such as teacher training in STEAM education and the influence of teaching practice, which led to the identification of conceptual dimensions for the implementation of STEAM education in formal educational contexts. In addition, gaps in the literature were identified, and implications for educational practice were discussed.

Related systematic reviews

This research involved a literature review through a systematic search based on impact and originality, carried out in the Scopus, ERIC, and WOS databases. One of the challenges encountered during the research process was the need to refine and adapt the study's guiding research questions. Below is the flow diagram (**Figure 2**) that systematizes the points found in the review.

Figure 2

PRISMA flow diagram



RESULTS

Study selection

The procedure followed in this study, as illustrated in Figure 2, began with the application of predefined inclusion and exclusion criteria. These were implemented through a search script across three databases: Scopus, which yielded 148 articles; Web of Science (WOS), with 20 articles; and ERIC, with 12 articles. The identification, screening, and eligibility process was carried out using the PRISMA methodology.

In the initial phase, 35 duplicate records were identified and removed. Additionally, 29 documents were excluded for being conference proceedings, books, theses, or other non-peer-reviewed sources. A further 20 articles were excluded for not meeting the inclusion criteria. Ultimately, a total of 96 peer-reviewed articles published between 2018 and 2024 were selected based on thematic relevance, methodological quality, and their specific focus on teacher training in STEAM education. The selected articles were exported and analyzed using a deductive method to extract evidence supporting the research question and validating the findings.

Characteristics of the included studies

The selected studies belong to the context of formal education, with a predominant focus on higher or university education, particularly in relation to teacher training and the conceptual dimensions of STEAM education that support its implementation. The studies mainly come from countries such as Indonesia, Thailand, Iran, Australia, the United States, Taiwan, Germany, Ghana, the Philippines, Spain, China, Finland, Japan, Uganda, Tanzania, India, Ecuador, Kenya, and the United Kingdom, demonstrating the interest and development in these regions regarding the consideration and influence of teacher training in STEAM education to ensure quality education, addressing the new demands of current contexts.

Key findings

This systematic literature review seeks to answer the research question by examining key aspects of the implementation of STEAM education in formal educational contexts, with teacher training in STEAM education positioned as a transversal and integrative axis.

This structure is based on the following guiding questions: What challenges and opportunities of 21st-century education are identified in the scientific literature regarding the implementation of STEAM/STEM education in formal educational contexts? and What holistic pedagogical and didactic integration approaches are described for STEAM learning in formal education?

The implementation of STEAM education in formal contexts involves substantial challenges, which are addressed through the identification of conceptual dimensions. Consequently, this study is guided by the following research question:

RQ1: What conceptual dimensions emerge from the systematic literature review for the implementation of STEAM/STEM education in formal educational contexts, with teacher training positioned as a central mediating dimension?

To address RQ1, it is essential to acknowledge that teachers must not only adapt to new technological and pedagogical demands, but also develop the competencies required to effectively integrate STEAM approaches. Within this framework, it is relevant to begin by recognizing the challenges and opportunities faced in twenty-first-century education.

Challenges and Opportunities in Twenty-First Century Education

In contemporary contexts marked by uncertainty, current challenges become opportunities to strengthen teaching practice through educational innovation. Hence, the importance lies in advancing curriculum updating, pedagogical innovation, methodological diversification, teacher training, the use of ICT, and engagement with the surrounding environment (González et al., 2024; Shaby et al., 2024)). In this way, the aim is to consolidate teaching models that are aligned with the needs of emerging dynamic, digital, and interdisciplinary educational trends.

The challenges and opportunities of twenty-first-century education focus on promoting cognitive development through practice (Abdurrahman et al., 2019) and on fostering students' skills and competencies through transdisciplinary approaches (Eronen et al., 2019). Accordingly, the development of mutual (Lavrinoviča, 2021), complex, and technological skills is required (Mutohhari et al., 2021). Moreover, interdisciplinary education is understood to influence the integration of scientific ideas (Song & Wang, 2021), providing a more comprehensive and applied understanding (Kim et al., 2019). In this regard, integrated approaches within STEAM education are those that effectively promote the development of these skills.

To foster interest in STEM at the primary education level, the teacher's role is crucial (Wulandari & Putri, 2024). At the secondary education level, studies by Shortlidge et al. (2024) and Xia et al. (2024) highlight factors such as mathematical preparation, academic ability, and self-efficacy. These elements, together with students' confidence in their academic skills and their sense of belonging within learning environments (Hedge, 2024; Dost, 2024), play a significant role. Therefore, it is essential to provide students with education in these areas alongside the development of twenty-first-century skills, which are fundamental for their adaptability and performance.

In this way, digital literacy and computational thinking are essential (Iwata et al., 2020), considering that digital literacy is grounded in the ethical use of technology (Reddy et al., 2022). This highlights the significant impact of collaboration within social environments (Yıldız & Ecevit, 2024; Xia et al., 2024), which strengthens students' performance in applied science contexts and real-world settings.

In the current era of artificial intelligence, computational thinking (CT) constitutes a key skill for digital citizens. Its integration into the school curriculum through STEAM projects (Sun et al., 2022; Sultan et al., 2025) contributes to innovation, creativity, and mathematical competence (Viro & Joutsenlahti, 2020). This integration is articulated through cooperative teaching approaches that facilitate interdisciplinary integration (Li et al., 2022). Likewise, virtual reality fosters greater concentration as well as physical and emotional development, complementing any form of instruction and helping students establish more durable connections with learning materials (Peterson & Stone, 2019). In this way, an articulation between theory and practice within global learning environments is promoted.

Holistic approaches to Pedagogical and Didactic to implement STEAM education in formal contexts

It is essential to identify the extent to which teacher training informs the pedagogical and didactic foundations necessary for the effective integration of STEAM education. Holistic approaches to STEAM learning emphasize not only the harmonious convergence of science, technology, engineering, the arts, and mathematics, but also the central role of the teacher in designing interdisciplinary learning experiences in real-world contexts (Tegegn, 2024). In the digital era, the teacher's role aligns with that of a digital leader who drives innovation, change, and holistic vision (Ming & Mansor, 2024), through the use of technological resources applied with pedagogical rigor.

Along these lines, the pedagogical and didactic integration of robotics enhances the teaching of programming, fosters computational thinking skills, and strengthens the application of STEAM content (Piedade et al., 2020; Tercariol et al., 2023). This aligns with the DIGCOMP framework perspective, in which teachers' digital competence becomes particularly relevant by linking the use of technology with pedagogical innovation and the personalization of learning. This is because it incorporates dimensions oriented toward the creation, management, and use of digital content (Tzafilkou et al., 2023; Althubyani, 2024). In this regard, Rodríguez (2022) emphasizes that digital content creation competence constitutes an essential sub-competence within contemporary models of teachers' digital competence. In such cases, teachers must understand their professional performance as the achievement of twenty-first-century competencias through digital teacher training.

From their perspective, references Dalle et al. (2021), Zenkina et al. (2021) y Zeng et al. (2024), note that when technological support is implemented in the classroom through gamification-based experimentation, universal skills are strengthened, as gamification itself contributes to their improvement (Putri et al., 2021), providing an innovative classroom environment. Additionally, the relationship between mathematics and programming is key (Holo et al., 2022), considering that the integration of graphics improves learning (Vojíř & Rusek, 2019). Moreover, REA (learning resources) videos require diverse competencies (Chiu, 2021). They emphasize learning, understanding, and continuous improvement, which are referred to as mastery goals (Struck Jannini et al., 2024).

Continuous assessment is crucial in online education (Yuebo et al., 2022), as the use of ICT significantly influences teaching, especially in rural areas (Zenda & Dlamini, 2023) and adult education (Abedini et al., 2021). It is evident that online learning has both advantages and challenges in its implementation (Hass et al., 2022). Reflecting the need to systematically articulate the STEAM curriculum system from four aspects: establishing the components of STEM competencies as an objective, designing the curricular content and teaching strategies, and conducting an effective evaluation to improve implementation (Hu & Guo, 2021).

In this way, STEAM develops a way of thinking by combining content coherently with active learning opportunities and multidisciplinary lessons that are engaging for students (Peters-Burton et al., 2019), with greater flexibility in the amount of information provided by teachers, more effortful processing, and greater collaboration (Tornee et al., 2019). Thus, the challenges of STEAM teaching require adaptation (Hsu et al., 2020), including the use of fabrication spaces (Kumpulainen et al., 2020), also known as makerspaces, that foster digital competence. These spaces are based on the Maker Culture (do-it-yourself), where teachers become key agents in technological integration (Silva et al., 2020). This addresses the need for continuous training and professional development to build digital skills in the knowledge society.

Mathematics education needs to adapt to this new reality, as current technological contexts have changed how people interact and think about the world around them. The pedagogical and didactic potential these resources provide in the teaching-learning process is imperative at both the basic and higher levels (Homa-Agostinho & Oliveira-Groenwald, 2020). This is why the use of multiplatform applications through ICT enables the development of mathematical skills from early education (Nicolete et al., 2018).

Career choices in science for secondary students depend on the influence of learning anxiety and exam anxiety, as well as chemical identity, which relates to beliefs of competence, performance, interest, external recognition, and holistic impressions (Guo, Hao, et al., 2022), it is crucial to foster identity in science, technology, engineering, art and mathematics (STEAM) fields to ensure retention (Guo, Deng, et al., 2022). Precisely, research skills and digital literacy in scientific education, particularly in academic writing with digital tools, generate greater competencies in the academic and professional environment (Blankendaal-Tran et al., 2023).

Likewise, when working with activities that promote reading comprehension, which require strategies and ICT (Pérez & Ricardo, 2022), as argumentative practices are essential in science (Eugenio-Gozalbo et al., 2022). Without a doubt, it can be consolidated that research-based learning, linked to age-appropriate challenging activities, better develops scientific skills (Khumraksa & Burachat, 2022). In this sense, research competence is attractive (Dullas & Soliven, 2021), because by using the reading of literary texts, a humanizing experience is promoted, helping to be more empathetic (Portolomeos & Rismo Nepomuceno, 2022). At the same time, it enhances their creativity in accordance with their cognitive needs and emotional adaptation (Merchán Gavilánez et al., 2024), considering that educational research arises from situational and individual interest (Hong et al., 2019).

Thus, to address major challenges, research-based pedagogical practices are employed (Keengwe, Ed., & Onchwari, Ed., 2019), including inquiry-based approaches and direct experiential learning that deeply strengthen emotional and cognitive knowledge (Salas-Aguayo et al., 2024). Accordingly, scientific skills are consolidated through strategies such as problem-based learning (He et al., 2022; Dudley, 2026), which foster critical thinking (Ma et al., 2021). To integrate real-world contexts, it is necessary to strengthen partnerships among schools, industry, and professional teaching communities (Ramírez et al., 2024). Despite these efforts, STEAM training remains limited in many countries, posing a threat to workforce development and economic competitiveness (Hernández-Pérez et al., 2024).

In response, current society demands professionals with STEM training (Smit et al., 2023) given the importance of teaching performance in the educational process. Their training implies professional development (Chen & Lai, 2022) that is achieved through dynamic attention to knowledge (MacDonald et al., 2021). Critical judgment depends on the selection of reliable information (Gómez-Pablos et al., 2020) that allows for the enhancement of critical thinking to maintain the capacity for judgment and avoid a technological dependence that limits informed decision-making (Gilli et al., 2024).

Therefore, Technical and Vocational Education and Training (TVET) programs are essential for developing the required capacities, encompassing both academic and non-academic skills, also known as whole-life youth development (WYD) skills (Ngware et al., 2022). Likewise, a more comprehensive understanding of science and engineering fields is necessary. To this end, it is suggested that their social and environmental impact be emphasized in the training of future teachers in STEAM education (Irmak & Öztürk, 2022). Responsibly ensuring quality in contextualized teaching practice.

In this regard, Rissanen et al. (2021), they suggest the pedagogy of growth mindset as it promotes emotional regulation, linked to training in data science, which in turn benefits young people, especially women to eliminate gender differences (Babirye et al., 2022). At the same time, to optimally achieve child development in low-resource environments, a holistic measurement is needed to enhance their adaptability (Bayley, 2022). Offering situated learning that addresses socio-emotional needs as a key element for their development.

During teacher education, it is necessary to identify ways to support pedagogical preparation by integrating design-based learning methods to enhance interdisciplinary learning within STEAM practices (Agudelo et al., 2024; Fernández et al., 2024; Grewe, 2025). In conjunction with explicit teaching strategies, the aim is to develop basic competencies and scientific knowledge in educational settings that emerge from learners' own sociocultural contexts. This approach is aligned with systemic teacher education and professional development for STEAM education.

In the design of educational experiences, strengthening self-concept and perceptions of STEM is essential, as higher levels of motivation, persistence, and willingness enable students to engage more actively in STEM activities and careers (Chen et al., 2024). For example, among secondary and vocational students, the inclusion of creative scientific research workshops has been shown to enhance scientific research self-efficacy (Lu et al., 2022). This implies that improvements in the self-efficacy of preservice primary teachers stem from cognitive experiences, simulated modeling, and positive emotional states (Webb & LoFaro, 2020), which contribute to more informed and optimal career choices (Jannini et al., 2024). Ultimately, the aim is to reduce preconceived limitations among students and educators regarding the desirability and accessibility of STEAM professions.

Culturally responsive strategies are then mentioned in university and professional STEAM courses and programs in general (Fletcher Jr. & Hines, 2022), and, as part of contextualizing learning, urban dance should be included in marginalized contexts; this implies educational approaches that question, reflect upon, and promote social and cultural awareness (Allen-Handy et al., 2021). Thus, it is seen as necessary to implement information on STEAM education for diverse students that includes integrating indigenous epistemologies and cultural pedagogy, equity, civics, and diversity to foster an innovative and technological society (Spycher Ed. & Haynes Ed., 2019). Since, within innovative pedagogies, gender-related responses vary depending on how learning experiences are designed (Zourmpakis et al., 2024). Positive interdependence is valued in the creation of contextualized learning scenarios and environments.

The inclusion of thematic connections between the 3D making movement, referring to educational activities focused on additive manufacturing (3D printing) within a maker and STEAM approach, and arts education and integrated curricular approaches with the arts is proposed. These approaches associate theoretical and practical elements with the design thinking methodology for the use of digital fabrication in the classroom (Knochel & Meeken, 2021). Therefore, the incorporation of the arts at all levels is suggested, recognizing their practical applications in reality (Thomas Ed. & Huffman Ed., 2020), personalizing curricula according to students' interests, allowing them to participate in university preparation activities, as well as in learning experiences based on collaborative work (Fletcher Jr. & Haynes, 2020) and social impact (Yıldız and Ecevit, 2024; Xia et al., 2024). Thus contributing to creativity, ingenuity, and innovation in problem-solving.

Similarly, literacy based on individual needs and the promotion of multiple literacies in line with the established curriculum through traditional or innovative teaching practices face tensions and challenges (Nygård et al., 2022). Essential skills for future teachers therefore include positive relationships, behavior management, and pedagogical competencies, with STEM, STEAM, and special education being the areas currently in demand (Austin et al., 2021). These possibilities can be realized provided that dialogic strategies supported by didactic resources that encourage self-reflection are incorporated (González-Rodríguez & García-Híjar, 2024), along with mechanisms that promote curricular integration and collaborative work (Amaya-Fernández et al., 2024). In this way, educational achievement is closely linked to the characteristics and certification of teachers (Nyatsikor et al., 2020). It is argued that their training is the mediating axis that articulates the effective implementation of STEAM education in formal contexts.

Thematic and relational analysis for the identification of conceptual dimensions

Table 4 presents the distribution of the selected articles (n=96) obtained through a systematic literature review using a search script focused on STEAM education in formal contexts. Thematic coding based on the conceptual mind map, keywords, and article abstracts allowed for the identification of five conceptual dimensions:

STEAM/STEM Education, Teacher Training, Professional Development, Teaching Practice, and 21st Century Skills. A single author may contribute to more than one of the five dimensions, as they are not mutually exclusive; the matrix details the frequency f and its corresponding percentage.

Table 4

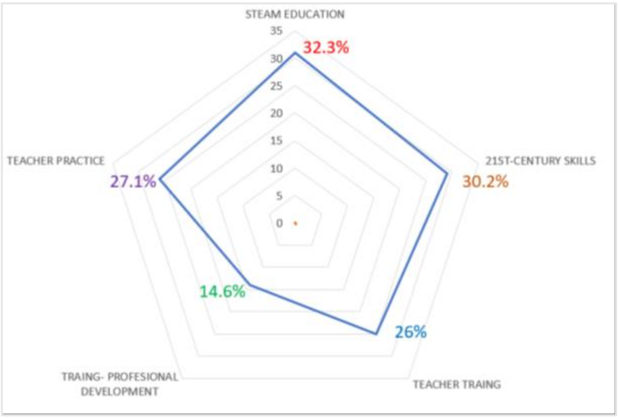
Distribution of conceptual dimensions, authors, frequency, and percentages

Model dimensions	Authors	*f*	% (of n =96)
STEAM/STEM Education	[3] Agudelo et al. (2024). [5] Allen-Handy et al. (2021). [12] Chen et al. (2024). [15] Dost (2024). [19] Fernández et al. (2024). [21] Fletcher Jr. & Hines (2022). [30] Hedge (2024). [31] Hernández-Pérez et al. (2024). [34] Hong et al. (2019). [35] Hsu et al. (2020). [36] Hu & Guo (2021). [37] Irmak (2022). [39] Jannini et al. (2024). [42] Kim et al. (2019). [46] Li et al. (2022). [56] Nicolete et al. (2017). [60] Park & Park (2020). [61] Peters-Burton et al. (2019). [71] Shortlidge et al. (2024). [73] Smit et al. (2023). [75] Spycher & Haynes (2019). [76] Struck Jannini et al. (2024). [77] Sun et al. (2022). [78] Tegegn (2024). [79] Tercariol et al. (2023). [80] Thomas & Huffman (2020). [86] Webb & LoFaro (2020). [88] Wulandari & Putri (2024). [89] Xia et al. (2024). [90] Ecevit (2024). [92] Zambak et al. (2021).	31	32.3%
Teacher traing	[3] Agudelo et al. (2024). [4] Althubyani (2024). [5] Allen-Handy et al. (2021). [10] Blankendaal-Tran et al. (2023). [11] Chen & Lai (2022). [14] Dalle et al. (2021). [16] Dullas & Soliven (2021). [18] Eugenio-Gozalbo et al. (2022). [24] González et al. (2024). [25] González-Rodríguez & García-Híjar (2024). [35] Hsu et al. (2020). [37] Irmak (2022). [42] Kim et al. (2019). [49] Ma et al. (2021). [51] Merchán et al. (2024). [54] Nagel (2021). [58] Nygård et al. (2022). [63] Piedade et al. (2020). [67] Rissanen et al. (2021). [75] Spycher & Haynes (2019). [83] Tzafilkou et al. (2023) [86] Webb & LoFaro (2020). [92] Zambak et al. (2021). [93] Zenda & Dlamini (2023). [95] Zenkina et al. (2021).	25	26.0%
Traing, Profesional development	[1] Abdurrahman et al. (2019). [3] Agudelo et al. (2024). [5] Allen-Handy et al. (2021). [7] Babirye et al. (2022). [18] Eugenio-Gozalbo et al. (2022). [32] Holo et al. (2022). [48] Lu et al. (2022). [51] Merchán et al. (2024). [60] Park & Park (2020). [63] Piedade et al. (2020). [69] Salas-Aguayo et al. (2024). [71] Shortlidge et al. (2024). [73] Smit et al. (2023). [81] Tornee et al. (2019).	14	14.6%
Teaching practice	[2] Abedini et al. (2021). [5] Allen-Handy et al. (2021). [17] Eronen et al. (2019). [32] Holo et al. (2022). [33] Homa-Agostinho & Oliveira-Groenwald (2020). [35]. Hsu et al. (2020). [36] Hu & Guo (2021). [37] Irmak (2022). [40] Keengwe & Onchwari (2019). [46] Li et al. (2022). [47] Lin, 2020. [56] Nicolete et al. (2017). [60] Park & Park (2020). [62] Peterson & Stone (2019). [63] Piedade et al. (2020). [64] Portolomeos & Rismo Nepomuceno (2022). [67] Rissanen et al. (2021). [72] Silva et al. (2020). [73] Smit et al. (2023). [78] Tegegn, 2024. [81] Tornee et al. (2019). [82] Tupas & Linas-Laguda, (2020). [86] Webb & LoFaro (2020). [87] Wu & Chen (2021).	26	27.1%
21st-century skills	[4] Althubyani (2024). [6] Austin et al. (2021). [8] Bayley (2022). [10] Blankendaal-Tran et al. (2023). [16] Dullas & Soliven (2021). [17] Eronen et al. (2019). [19] Fernández et al. (2024). [22] Gilli et al. (2024). [23] Gómez-Pablos et al. (2020). [36] Hu & Guo (2021). [38] Iwata et al. (2020). [41] Khumraksa & Burachat (2022). [44] Kumpulainen et al. (2020). [45] Lavrinoviča (2021). [48] Lu et al. (2022). [49] Ma et al. (2021). [53] Mutohhari et al. (2021). [54] Nagel (2021). [55] Ngware et al. (2022). [58] T. & N. (2022). [63] Piedade et al. (2020). [66] Reddy et al. (2022). [74] Song & Wang (2021). [77] Sun et al. (2022). [83] Tzafilkou et al. (2023). [88] Wulandari & Putri (2024). [90] Ecevit (2024). [92] Zambak et al. (2021). [95] Zenkina et al. (2021).	29	30.2%

Figure 3 presents the detailed information on these frequencies, which reflect the centrality of teacher training processes as a cross-cutting axis in the implementation of the STEAM/STEM approach in formal education. This is achieved by identifying general trends and levels of conceptual centrality within the reviewed documentary corpus.

Figure 3

Distribution of the conceptual dimensions identified in the literature on STEAM/STEM education (n = 96)



Note: Figure 3 represents the percentage distribution of the five conceptual dimensions that emerged from the systematic literature review: STEAM/STEM education, teacher training, professional development, teaching practice, and 21st-century skills. The values reflect the frequency of each dimension in the analyzed studies and allow visualization of its relative weight within the proposed conceptual model.

Figure 3 presents the thematic distribution of the 96 articles analyzed according to the identified dimensions. It shows that STEAM/STEM education is the most prevalent dimension in the literature (32.3%), demonstrating its recurrence as a central axis structuring the analyzed studies. Teaching practice (27.1%) and teacher training (26%) correspond to dimensions with strong conceptual weight. Professional development and training (14.6%) complements this, often being directly associated with teacher training, and together they achieve considerable recurrence within the research (40.6%). Likewise, 21st-century skills (30.2%) demonstrate a high recurrence in the analyzed educational approaches.

Thus, the results of the systematic literature review allowed for the identification of a set of conceptual dimensions that structure the implementation of STEAM/STEM education in formal educational contexts

Conceptual model derived from the relational analysis of conceptual dimensions

From the relational analysis of the dimensions matrix, a conceptual semantic network model was developed by examining the co-occurrence and conceptual density of dimensions using the relational logic of the qualitative analysis software Atlas.ti, aimed at the implementation of STEAM/STEM education in formal educational contexts (Figure 4).

It is evident that STEAM/STEM education is configured as the structural core, while teacher training functions as a central mediating dimension, articulating training processes, teaching practice, and the development of 21st-century competencies. The remaining dimensions are dynamically and continuously interrelated, reflecting a non-linear and interdependent structure that enables holistic pedagogical and didactic integration in STEAM education. The relative size of the nodes reflects their frequency and conceptual centrality within the analyzed literature. An overview diagram summarizing these relationships is presented below (Figure 5)

Figure 4

Conceptual dimensions model for the implementation of STEAM/STEM education in formal educational contexts

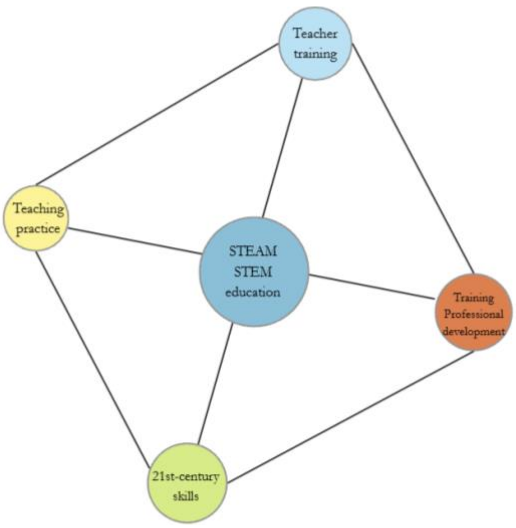
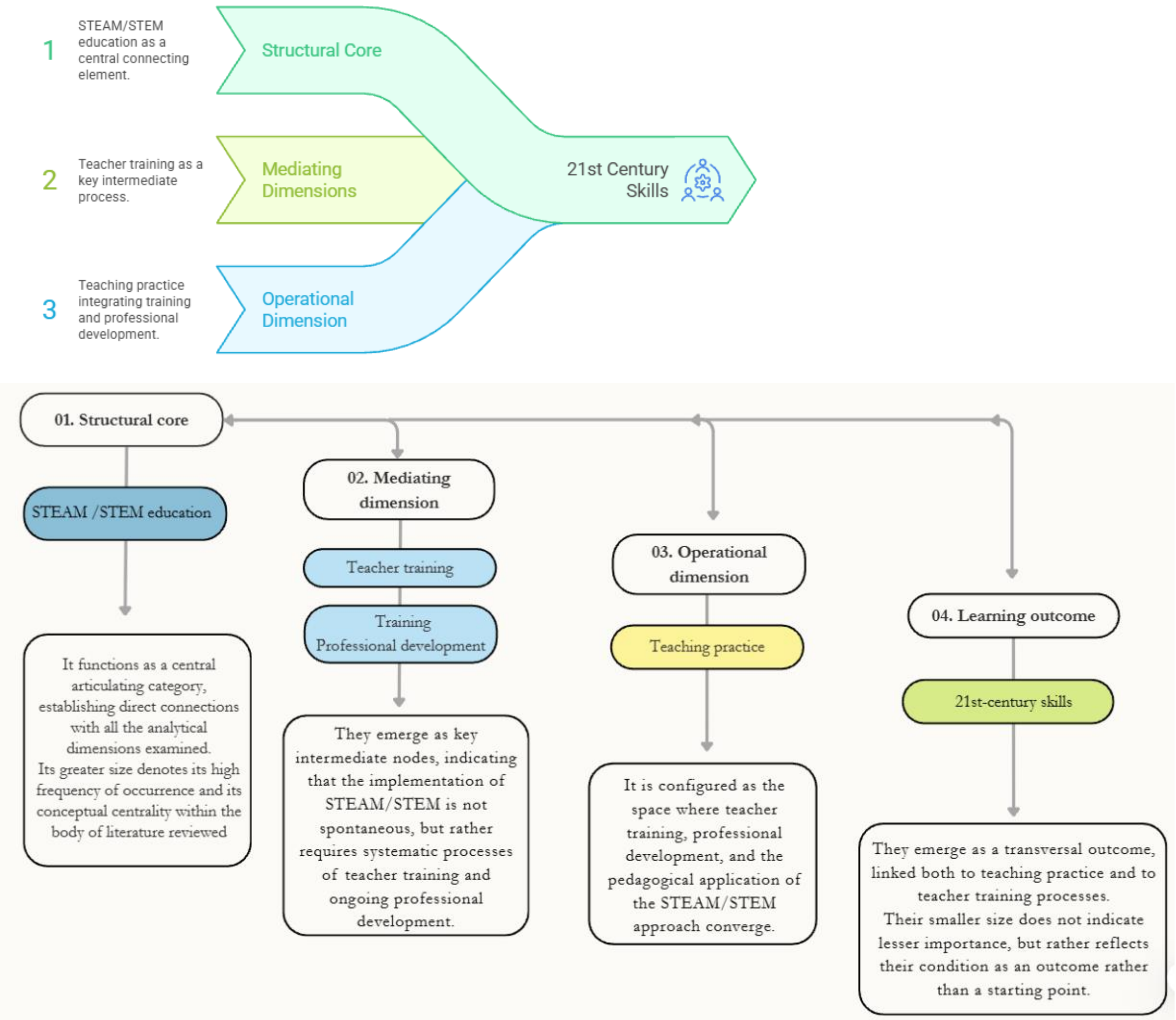


Figure 5

Integrated conceptual model for the implementation of STEAM/STEM education



Identified gaps for potential future revisions

Due to the growing demand for new approaches to address current educational needs, most geographic regions still lack adequate teacher training in STEAM education. This contributes to the limited scholarly output on this issue, as well as to the constraints faced by regions where there is no direct influence of educational policies aligned with international standards. This includes contexts where curricula have yet to implement the interdisciplinary nature of STEAM in educational projects developed in response to global challenges.

Finally, there is limited research on the methods and tools used to assess the effectiveness of teacher training programs in STEAM, especially in terms of measuring the development of students' cognitive and affective skills. These gaps offer clear directions for future research that could enrich the understanding and impact of teacher training in STEAM across diverse educational contexts, leading to the proposal of a teacher training model in STEAM.

CONCLUSIONS

Based on this review of 96 studies relevant to the present research and aligned with the research question, the need to implement a STEAM curriculum becomes evident. This curriculum should be grounded on four key aspects: STEAM competencies as educational objectives, curriculum design supported by teaching strategies, effective assessment to foster continuous improvement, and adaptation to new educational contexts and the evolving profile of 21st-century learners. As an interdisciplinary and multidisciplinary approach or methodology, STEAM contributes to solving real-world problems through action, active and collaborative participation, and thus promotes the development of communicative, socioemotional, multidisciplinary, critical thinking, and digital competencies, particularly in learning environments such as makerspaces.

By its nature as a dynamic and bidirectional process, teacher training plays a crucial role in improving educational quality, enabling the development of both academic and non-academic skills through Technical and Vocational Education and Training (TVET) programs. To contribute to closing the gender gap, it is proposed to incorporate strategies such as self-efficacy in scientific research and interdisciplinary learning, articulated with ancestral practices and culturally responsive pedagogy. This framework fosters rootedness, identity, equity, adaptability, and diversity in education. Moreover, integrating the Arts into this educational proposal enhances creativity, curiosity, ingenuity, and innovation across diverse learning settings through a holistic perspective.

The inclusion of STEAM (Science, Technology, Engineering, Arts, and Mathematics) in contemporary educational contexts through an interdisciplinary lens enables better adaptation to the knowledge era—mediated by information technologies, artificial intelligence, and decision-making optimization—guided by creativity and innovation. This initiative supports the enhancement of teaching practices and the ongoing professional development of educators in STEAM education, enriched by the adoption of innovative pedagogical approaches such as Process-Oriented Guided Inquiry Learning (POGIL). Combined with real-world media resources, this approach fosters immersive, meaningful, and sustainable learning experiences tailored to the needs and profiles of 21st-century learners.

Thus, integrating innovative approaches into contemporary education is essential to prepare students for the challenges of the 21st century. From scientific literacy to fostering creativity and problem-solving skills, these approaches have the potential to transform how we teach and learn, promoting equitable and high-quality educational development.

In this way, the integration of innovative approaches in contemporary education is essential to prepare students for the challenges of the 21st century. This systematic literature review made it possible to consolidate a conceptual model that explains the implementation of STEAM education in formal educational contexts through a set of interrelated dimensions. The results, synthesized using a descriptive and analytical approach through thematic and relational qualitative analysis, show that the STEAM education dimension is positioned as the core that structures the conceptual model.

Teacher training reflects a central mediating dimension which, together with training and professional development, evidences a strong trend of interest in the role of teachers as the core of pedagogical and didactic implementation in formal educational contexts. Teaching practice represents a strategic component for strengthening performance in terms of practical know-how. Likewise, 21st-century competencies are consolidated as a transversal outcome of the model, closely linked to contemporary educational approaches.

The model shows that the effective implementation of STEAM education does not occur spontaneously; rather, it emerges from structured and continuous training processes through the integration of holistic, pedagogical, and didactic approaches aligned with the new educational scenarios arising from the knowledge society. Likewise, the identification of conceptual dimensions and gaps in the literature constitutes a theoretical contribution that guides future lines of research and provides relevant criteria for decision-making in educational practice, enabling responses to the challenges and opportunities of 21st-century education.

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Ethical statement

This study follows ethical standards for academic research. It is based on a systematic literature review of previously published sources, without involving human participants or personal data. All references were properly cited, and the analysis was conducted with transparency, academic integrity, and methodological rigor.

Competing interests

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

The authors jointly contributed to the conception and design of the study, the preparation of the manuscript, the critical review and final approval, and agree to be responsible for all aspects of the work.

Data availability

The data supporting the findings of this study are derived from publicly accessible sources, primarily scientific articles indexed in academic databases. The information analyzed can be consulted through the bibliographic references included in the manuscript. No primary datasets were generated, and no confidential data were used.

AI disclosure

The authors acknowledge the use of ChatGPT to support the English translation of the manuscript. The prompts used include **"**Translate the following text into academic English." The output from these prompts was used to translate sections of the manuscript, which were later reviewed and edited by the authors. While the authors acknowledge the usage of AI, the authors maintain that they, Andrea Segarra-Morales and Francisco P. Rodriguez-Miranda, are the sole authors of this article and take full responsibility for the content therein, as outlined in COPE recommendations.

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