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Which Maker and STEAM integration styles stand out in education? A systematic review of pedagogical practices in teacher education

Lisiane Barcellos Calheiro[1] · **Ileana M. Greca**[2]

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Abstract

The growing demand to prepare teachers to face 21st-century educational challenges has driven the adoption of active methodologies, including the integration of STE(A)M education and the Maker model. These approaches foster critical thinking, creativity, and collaboration through practical skills and interdisciplinary experimentation. This study systematically reviews the literature to identify styles of Maker model integration in science teacher education at the basic education level, as well as challenges and strategies for its implementation. The analysis revealed a predominance of the collaborative style, followed by subordinate and peripheral approaches. Most studies reported positive impacts on teaching confidence, technical skills, and interest in innovative pedagogical practices. However, challenges such as limited curriculum time, restricted access to resources, and the need for continuous training hinder effective implementation. Additionally, the Maker model remains underrepresented in developing countries, highlighting the need for further research across diverse cultural and economic contexts. Integrating the Maker model with STE(A)M education significantly enhances teacher training, fostering a more dynamic and innovative learning environment. However, successful implementation requires institutional support, curriculum alignment, and ongoing professional development. The study underscores that different integration styles—collaborative, peripheral, and subordinate—must be adapted to teachers' needs and educational systems. While findings are promising, broader analyses are needed to strengthen the empirical foundation on the impact of these methodologies in basic education.

Keywords STE(A)M Education · Maker Model · Teacher Training · Basic Education

✉ Ileana M. Greca
imgreca@ubu.es

[1] Instituto de Física, Universidade Federal de Mato Grosso Do Sul, Campo Grande, MS CEP 79070-900, Brazil

[2] Department of Specific Didactics, Universidad de Burgos, Burgos, Spain

Introduction

The changes in official guidelines that shape Basic Education curricula in various countries reflect the advancements of contemporary society. Upon completing this stage, students are expected to synthesize large amounts of available information and leverage interdisciplinary knowledge to address complex real-world issues (D'Ambrosio, 2020; Jia et al., 2021; Nadelson & Seifert, 2017). In line with these guidelines, teachers are encouraged to prioritize the development of theoretical and practical skills aimed to apply in real-life school situations.

Segarra-Morales and Uca-Aulestia (2024) argue that teachers, from their initial training to their development as specialists, face the challenge of preparing students to solve complex problems and promoting the development of essential 21st-century skills. Furthermore, they are expected to adopt student-centered pedagogical approaches, promoting learning through active methodologies and problem-solving (Gama, 2023). Geitz et al. (2016) emphasized the importance of creating learning environments where students acquire knowledge through complex and meaningful real-life experiences. This perspective reinforces the need to reconsider teacher education, aligning it with the challenges and expectations of the contemporary educational perspective.

In this context, the STE(A)M and Maker approaches assume a significant position as both promote methodologies that encourage students'active engagement, providing opportunities to develop skills such as critical thinking, creativity, problem-solving, communication, and teamwork in real-world conditions (Mariana & Kristanto, 2023; Lorenzin, 2020; Jia et al., 2021; Dare et al., 2019).

The STEM approach emerged in the United States in the 1990s to designate careers and curricula focused on Science, Technology, Engineering, and Mathematics. It was driven by the low performance of American students in scientific subjects and the need to promote significant improvements in this area of education (Sanders, 2009; Toma et al., 2024). The integration of the arts into the STEM approach—known as STEAM—quickly became established within the scientific and technological education field, increasingly earning the focus of research (Sheth & Pathak, 2023; Toma et al., 2024; Tytler, 2020; Zandvliet, 2023). This emphasis reflects a major shift in teaching approaches, transitioning from simply acquiring technical knowledge to incorporating practical application, creativity, and interdisciplinarity—crucial for addressing complex challenges. The goal is to go beyond a focus on basic academic performance, prioritizing the development of essential skills for problem-solving and innovation (Quigley & Herro, 2016; Sheth & Pathak, 2023). Although STEAM education is a relatively recent approach, its potential has been proven; however, it still requires further exploration at all educational levels, with particular attention to teacher training (Ortiz-Revilla et al., 2021).

Maker education or Maker spaces, complement this approach by promoting a"do-it-yourself"learning mindset, enabling students to experiment and create through hands-on activities and collaborative projects. This viewpoint considers learning a social and collaborative process centered on design and the production of physical objects (Halverson & Sheridan, 2014). Maker spaces have gained prominence in education, promising to enhance student learning by integrating knowledge in science and technology while encouraging the development of 21st-century skills such as creativity, innovation, and entrepreneurship (Halliburton et al., 2024; Jin et al., 2021; Wang & Shan, 2019).

Although the Maker movement originated in the American DIY (Do It Yourself) culture of the 1950s (Lindberg et al., 2020; Sturmer & Mauricio, 2021), the way it is known today began to organize in the early 2000 s with the emergence of dedicated fabrication and innovation spaces, known as"makerspaces"or"FabLabs"(Browder et al., 2019; Holm, 2021). In recent years, Maker culture has been integrated into formal and informal educational settings (Martin, 2015; Calabrese Barton & Tan, 2018; Li et al., 2024). It has attracted significant interest from educators due to its potential to deeply engage students in learning across various fields of knowledge (Bevan, 2017; Bullock & Sator, 2015). Schools and universities have adopted Maker spaces as an effective strategy to engage students in more active and hands-on STE(A)M education (Martinez Jr., 2020; Love, 2022; Chen et al., 2024). In this context, the integration of educational activities with these spaces has gained prominence, driving the creation and use of environments specifically designed to support learning through experimentation and making (Andrews & Boklage, 2024; Kay & Buxton, 2023; Barrett et al., 2015; Martin, 2015). Incorporating these approaches into educational practices highlights the importance of empowering teachers. For teachers to truly embrace the STE(A)M approach integrated with a Maker model, it must be introduced during initial teacher training, providing a solid foundation from the beginning of their professional journey. This training should go beyond theoretical foundations, offering practical experiences that enable educators to apply these concepts flexibly and contextualized in the classroom.

Considering the topic's relevance for teacher education and aiming of mapping publications on integrated practices of Maker education and STE(A)M in teacher training for science teaching, we conducted a systematic literature review covering the past decade. In this context, we seek to answer the following research questions:

Q1: What integration styles between the Maker model and STEM/STEAM education are being incorporated into teacher training for science teaching in basic education?
Q2: What are the main challenges and strategies identified in the literature to promote the integration of the Maker model into STEM/STEAM education in teacher training?

We highlight that although the STEM and STEAM approaches differ in focus and scope in terms of research and didactic application (Kelley & Knowles, 2016; Cartagena et al., 2017; Zamorano Escalona et al., 2018; Aguilera & Ortiz-Revilla, 2021; Rasul et al., 2018; Wannapiroon & Petsangsri, 2020), this paper aims to determine how Maker education has been used with both approaches.

Methods

This systematic review examines educational proposals that promote the integration of STEM and/or STEAM education and the Maker model within the context of teacher training for basic education. To achieve this goal, the research was organized into two stages: (1) identification of educational proposals aimed at science teaching that incorporate this integration, implemented within teacher training programs; and (2) analysis of the integration models in the identified proposals, focusing on assessing how the articulation between STE(A)M education and the Maker model contributes to the development of effective pedagogical practices in science teacher training.

Search strategy

Following the international PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021) for article selection, we applied well-defined inclusion criteria, clearly described as recommended by Higgins and Green (2008). The process of searching, identifying, screening, and including the studies was conducted through the CAPES (Coordination for the Improvement of Higher Education Personnel—Brazil) Journal Portal in October 2024, covering the Web of Science (WoS) database by Clarivate Analytics and Scopus by Elsevier. The search was limited to the period from 2013 to 2024. The choice of these databases aims to ensure the quality and relevance of the selected publications, as the indexed journals meet rigorous criteria, including peer review and adherence to internationally recognized ethical standards.

We conducted the study search through advanced queries using the keywords "STEM Education" , "STEAM Education" , "Maker culture" , "Maker space" , "Makerspaces" , "training teachers" , and "Teacher Education", all connected by the boolean logical operators "OR" and "AND", as outlined in Table 1.

The results presented in Table 1 were refined to ensure greater accuracy and relevance of the data, eliminating potential inconsistencies and highlighting essential information for the analysis. The Scopus database initially identified 361 results, as illustrated in Fig. 1. These results were refined, starting with a temporal limitation between 2013 and 2024, which did not alter the records initially found. Secondly, the social sciences subject area was selected, which reduced to 304 results. Thirdly, the document type was restricted to articles published in journals and in English, Portuguese, and Spanish languages, resulting in 210 studies.

In the Web of Science (WoS) database, we applied the same search string used in Scopus, initially finding only six results. We applied the temporal criterion to refine the search, limiting the publications to a decade (2013 to 2024), obtaining the same six results. Next, we selected the area of education research, which resulted in four results. Finally, to ensure the quality of the studies, only peer-reviewed articles in English, Portuguese, and Spanish were selected, yielding three results. After refining both databases, WoS and Scopus, we obtained 192 results for the review analysis.

By analyzing the title, abstract, and keywords of the selected articles, the following inclusion criteria were applied:

1. The article must address the integration of STEM/STE(A)M education and the Maker model in teacher training, mentioning these aspects in the title, abstract, or keywords. This first-level screening led to the exclusion of 136 articles, resulting in a preliminary

Table 1 Number of results for each search string

Database	Search String	Results
Scopus	("STEM Education"OR"STEAM Education") AND ("Maker culture"OR"Maker space"OR"Makerspaces") AND ("training teachers"OR"Teacher Education")	361
WoS	("STEM Education" OR "STEAM Education") AND ("Maker culture" OR "Maker space" OR"Makerspaces") AND ("training teachers" OR "Teacher Education")	6

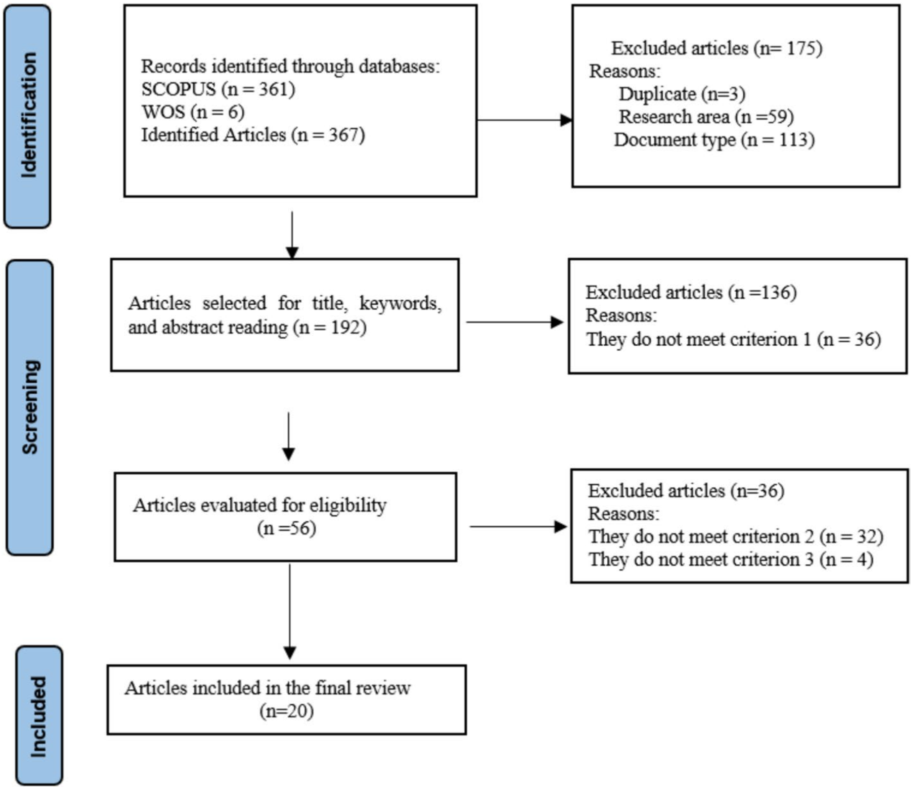

Fig. 1 Flowchart of the selection process (adapted from Page et al., 2021)

corpus of 56 articles. Importantly, a second level of analysis was then conducted through full-text reading of these 56 articles. At this stage, two additional inclusion criteria were applied:

2. The article must propose an explicit integration of the Maker model with educational goals, such as the development of STEM/STE(A)M-related competencies and skills in teacher training.
3. The article must focus on teacher education for basic education contexts.

These second-level criteria were not intended to filter articles during the initial selection but rather to refine the scope of the final synthesis. Thus, the review was conducted in two stages: first, a broad overview of relevant literature (56 articles), followed by a more focused synthesis of studies that met the refined criteria for depth analysis (20 articles). Figure 1 presents the PRISMA flowchart, which illustrates the stages of the systematic review process.

The selected articles demonstrate academic quality and relevance to the research topic. In this study, although a formal quality assessment scale was not applied, the selection of the 20 articles included in the final synthesis followed a rigorous process. Multiple readings were conducted, and predefined inclusion and exclusion criteria were applied to ensure that the studies analyzed demonstrated theoretical consistency, thematic alignment, and potential for scientific contribution. Furthermore, most of the selected articles were published in high-quality, peer-reviewed journals indexed in internationally recognized databases such as Scopus and Web of Science, which reinforces the reliability and academic rigor of the reviewed material.

Procedure for analysis

For an in-depth analysis of the selected studies, we established criteria to assess the integration of STE(A)M education with the Maker model, similar to the various categories of styles proposed by Sanz-Camarero et al. (2023a, 2023b) for the integration of arts in interdisciplinary proposals. Table 2 contains the representation of these styles and their definitions. The data categorization was conducted independently by the authors. Any discrepancies identified during this process were discussed and resolved by consensus, ensuring the reliability of the analysis.

In this study, we adopt the term "Maker model" to broadly, integratively, and coherently encompass the various aspects and contexts of the Maker approach in education. The literature presents a variety of related expressions, such as "Maker culture" – which emphasizes community values like creativity and collaboration (Blikstein et al., 2016; Mersand, 2020); the "Maker movement" – referring to the broader social and technological phenomenon centered on practical innovation and hands-on creation (Martin, 2015; Vuorikari et al., 2019); and "makerspaces" or "Maker laboratories" – which highlight the physical environments designed for digital fabrication and collaborative creation (Bevan, 2017; Brahms & Crowley, 2016; Namukasa et al., 2023a, 2023b). While these terms reveal important dimensions of the phenomenon, we argue that the term "Maker model" provides a more comprehensive and structured perspective, as it brings together principles (such as autonomy and collaboration), practices (such as prototyping and iteration), and educational goals (such as fostering creativity and problem-solving), thus forming a pedagogical framework aligned with the aims of this research.

Results and discussion

The results of this research are organized into three sections. First, we provide an analysis of the complete sample, followed by a description of the general parameters of the corpus to be analyzed, providing a broad overview of the studies. Finally, we conducted a detailed analysis of the review, focusing on the central characteristics of the integration between STE(A)M Education and the Maker model, highlighting the specificities and contributions of each work to the investigated field.

Overview of the articles selected for the broad analysis: General trends

The sample of 56 articles proved to be representative of the characteristics that define scientific research on the integration of STE(A)M education and the Maker model. The analysis presented in this subsection refers to the entire set of 56 articles selected after the screening phase, aiming to offer a broad understanding of the overall trends and gaps in the literature. The preliminary analysis indicated a growth trend in publications over the past decade (Fig. 2). We observed that most of the research is concentrated

Table 2 Description and representation of integration styles between STEAM education and the Maker model

Style	Definition	Model representation
Subordinate	The Maker model is used as a tool to enrich learning in the STEAM fields without a central focus on its principles and practices. The emphasis is on the final product related to the subjects rather than the Maker process itself. Example: Students can use Maker tools and techniques, such as 3D printing or basic circuits, to develop a scientific experiment or illustrate a model.	
Peripheral	The Maker model is integrated more substantially but remains secondary to other areas. While this approach introduces Maker concepts, the primary focus of learning is STEAM, with Maker as a complementary tool to reinforce these fields. Example: During a study on energy transfer as heat, students build prototypes of thermal bottles using various materials, testing their insulation capacity and exploring the concepts of conduction, convection, and radiation.	
Collaborative	The Maker model acts as an equal partner alongside other STEAM disciplines. This integration connects the principles of the Maker model with scientific, technological, and engineering concepts, providing students with a deep, hands-on, and interdisciplinary learning experience. Example: In an interdisciplinary project on climate change, students investigate the causes and impacts of the issue while designing and building devices to monitor CO_2 levels, using sensors and programming on platforms like Arduino.	

Table 2 (continued)

Main Focus	The Maker model plays a central role, directly driving the learning process. This approach positions the Maker model as the primary perspective for understanding and solving real-world challenges, placing hands-on learning and innovation at the core of the educational experience. Example: The central problem is designing solutions to improve accessibility for visually impaired individuals in a museum. Students would research existing solutions and then design and build their innovative solutions, using a STEAM field to design and refine their project using Maker tools and techniques.	
Exclusive Focus	The Maker model focuses exclusively on exploring and developing fundamental skills and principles. This approach promotes a learning experience centered on autonomy, innovation, and the practical application of essential Maker concepts. Example: A Maker course or workshop to teach various Maker skills, such as coding, electronics, woodworking, or digital fabrication. Students learn to program and build automated robots, exploring all stages of the process—from design and assembly to programming sensors for autonomous navigation	

from 2021 to 2023, reflecting the increased interest in this topic in recent years, with a significant peak in 2023, totaling 16 publications.

This growth pattern is likely linked to the increasing demand for innovative teaching methods fueled by technological advancements and changes in educational practices (Boakes, 2020). The decrease observed in 2024 can be explained by the temporal proximity, suggesting that some articles expected for this year were not published yet. However, when examining articles specifically proposing integrating the Maker model with STEAM education in teacher training, there is a significantly small quantity compared to the total number of publications. These proposals peaked in 2023, with the analysis of articles highlighting an emerging trend still in the process of consolidation in the educational field.

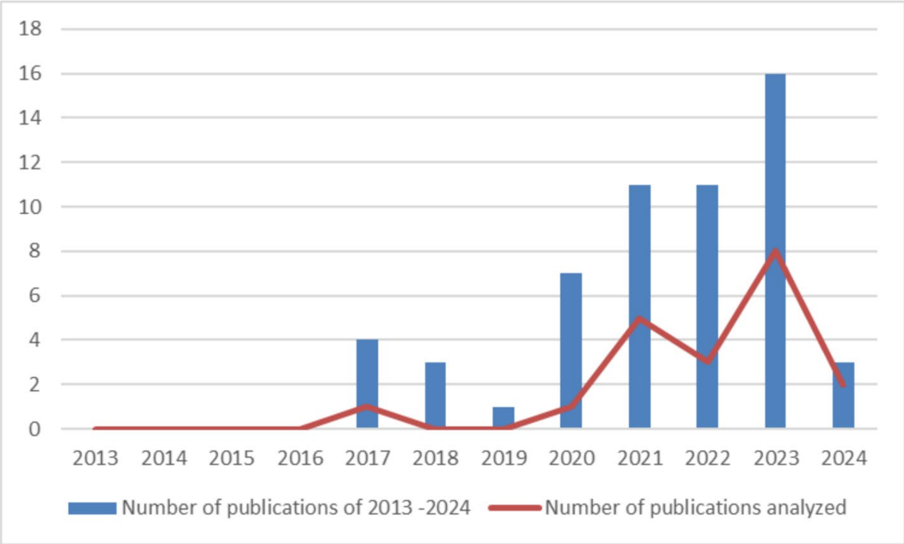

Fig. 2 Relationship between the total number of publications and the total number of articles analyzed in this study

General description of the articles selected for the in-depth analysis

Following the broader analysis of the 56 articles identified during the screening phase, this section focuses specifically on the 20 studies selected for final synthesis. These articles were chosen based on their direct relevance to the integration of STEAM education and the Maker model in teacher training, either in initial or in-service contexts. An overview of the key parameters of these selected studies is presented in Table 3. This focused analysis allows for a deeper understanding of the pedagogical strategies, contexts, and educational levels addressed by the most relevant literature on this topic.

Table 3 presents the analyzed studies in various countries, including England, Australia, China, Canada, the USA, Spain, Brazil, and Sweden. The presence of various countries reflects the global nature of research on integrating STE(A)M education and the Maker model. The predominance of countries such as the USA, Canada, and Australia in academic production underscores the leadership of nations with well-structured educational policies and funding for research and innovation. The United States leads the way in publications, with nine studies, and is notable for its emphasis on STEAM, reflecting a trend toward integrating the arts into STEM disciplines. Canada ranks second, with four studies covering different contexts. The predominance of North American researchers in this field is directly linked to the fact that the USA is recognized as the birthplace of the Maker movement. With a deeply rooted"do-it-yourself"culture in its history, the country has driven the development of practices and research in STE(A)M and Maker (Anderson, 2012; Halverson & Sheridan, 2014; Reynante et al., 2020).

In Europe, countries such as England, Sweden, and Spain contribute with studies on teacher training for primary and secondary education, with a notable focus on the large-scale implementation of STEAM in pre-service teacher training in Spain. There is also interest in using STEM in Asia and Oceania, represented by China and Australia. The geographical analysis reveals that the integration of STE(A)M education and the Maker

Table 3 General parameters of the analyzed articles

Authors	Year	Country	Journal	Sample	Educational approach
Halliburton et al	2024	Australia	Research in Science Education	PS ($n = 12$)	STEM
Kay & Buxton	2024	England	Journal of Early Childhood Research	IS (ND)	STEM
Xiang et al	2023	China	International Journal of Child-Computer Interaction	IS ($n = 24$)	STEM
Namukasa et al	2023	Canada	International Journal of Teacher Education and Professional Development	PS ($n = 114$)	STEM
Ramey &Stevens	2023	United States	Teaching and Teacher Education	IS ($n = 29$)	STEAM
Douglass	2023	United States	Education Sciences	PS ($n = 4$)	STEM
Fields & Kafai	2023	United States	Sustainability	IS ($n = 8$)	STEAM
Perez et al	2023	Spain	Revista Iberoamericana de Educación a Distancia	PS ($n = 162$)	STEAM
Namukasa et al	2023	Canada Brazil	ZDM – Mathematics Education	IS and PS ($n = 30$)	STEM
Gravel & Puckett	2023	United States	International Journal of STEM Education	IS ($n = 11$)	STEM
Walan & Gericke	2023	Sweden	International Journal of Technology and Design Education	IS ($n = 11$)	STEM
Hughes et al	2022	Canada	International Journal of Educational Research Open	IS ($n = 2$)	STEAM
An et al	2022	United States	TechTrends	PS ($n = 13$)	STEAM
Shin et al	2021	United States	Journal of Research on Technology in Education	IS ($n = 15$)	STEM

Table 3 (continued)

Authors	Year	Country	Journal	Sample	Educational approach
Hughes et al	2021	Canada	Canadian Journal of Learning and Technology	IS ($n = 85$)	STEAM
Shively et al	2021	United States	Journal of Education	PS ($n = 10$)	STEAM
Lummis et al	2021	United Kingdom	Australian Journal of Teacher Education	IS (ND)	STEM
Douglass & Verma	2021	United States	Journal of Science Teacher Education	IS ($n = 2$)	STEM
Quigley et al	2020	United States	Journal of Science Education and Technology	IS ($n = 23$)	STEAM
Blackley et al	2017	Australia	Australian Journal of Teacher Education	PS ($n = 10$)	STEM

IS – In-service teachers; *PS* – Pre-service teachers; *ND* – Not declared model is still underrepresented in developing countries, such as Latin America, highlighting the need to promote research in diverse cultural and economic contexts to enrich global perspectives.

When analyzing educational approaches, the predominance of STEM is evident, accounting for 60% of the studies analyzed. This approach is associated with more technical contexts, focusing on using technologies and developing scientific competencies. It is applied in pre-service and in-service teacher training. In contrast, 40% of studies show STEAM, indicating a growing trend to integrate creativity and innovation into the technical curriculum. This difference suggests that STEM is more established from an educational perspective, while STEAM, although rising, still shows less exploration.

The analysis of the samples used in the studies reveals significant variation in size, reflecting different research objectives and suggesting the coexistence of both broad and specific investigations. Studies with large samples, such as those by Perez et al. (2023) ($n=162$) and Namukasa et al. (2023a, 2023b) ($n=114$), use statistical approaches, while research with small samples, such as those by Douglass and Verma (2021) ($n=2$) and Hughes et al. (2022) ($n=2$), adopted a qualitative method. The different sample sizes reflect the methodological flexibility of the research. However, the inconsistency complicates comparisons between studies and the validation of results.

Regarding teacher training, the analyzed studies indicate a fairly equitable distribution between pre-service training (PS) and in-service training (IS). Pre-service training, aimed at preparing future educators, is present in 8 studies, representing 40% of the corpus. Examples include the research of Namukasa et al. (2023a, 2023b) and Douglass (2023), which explore strategies for integrating the Maker model and STE(A)M in the training of new teachers.

On the other hand, in-service training, which focuses on the updating and professional development of practicing teachers, predominates in publications, and appeared in 12 studies, corresponding to 60% of the corpus. This reflects the demand for strategies that help educators incorporate innovative methodologies, such as integrating STE(A)M with the Maker model, to meet the demands of contemporary education.

The analysis of the journals that published the 20 selected articles for this review reveals a predominance of publications with recognized academic relevance and international visibility. Most of the studies were published in high-prestige journals indexed in leading databases such as Scopus, Web of Science, and Springer, including Teaching and Teacher Education, ZDM – Mathematics Education, and the International Journal of STEM Education. Additionally, several journals have a scope directly related to teacher education, STEM/STEAM education, and the integration of educational technologies, such as the Journal of Research on Technology in Education, the International Journal of Technology and Design Education, and Education Sciences. This set of factors reinforces the quality, academic rigor, and thematic relevance of the studies included in the final synthesis.

In-depth analysis: STEAM-Maker integration styles

This section presents an in-depth analysis of how the Maker model is integrated into STE(A)M education in the selected studies. The investigation was conducted based on previously established criteria, grounded in the reviewed literature—particularly the categories of integration styles for the arts in interdisciplinary proposals, as described by Sanz-Camarero et al. (2023a, 2023b). The analysis begins with the presentation of the identified integration styles (see Table 4), which allow for the categorization of different approaches to articulating the Maker model with the components of STE(A)M education.

Table 4 Description of the articles for in-depth analysis

Author(s)/Year	Style	Educational Stage	Practical Integration Proposal	Evaluation	Instruments	Results
Halliburton et al. (2024)	Subordinate	Primary Education	Project-Based Learning	Qualitative	Semi-Structured Interview Design Portfolio	Positive impact on teachers' confidence to teach. Ability to learn how to use equipment
Kay and Buxton (2023)	Collaborative	Preschool	Project-Based Learning	Qualitative	Semi-Structured Interview	Positive impact on STEM knowledge and practice
Xiang et al. (2023)	Peripheral	Preschool	"Making a Makerspace"Program	Qualitative	Questionnaire	The program encouraged them to adopt a reflective practice. They highlighted challenges such as the need for more comprehensive training, time constraints in the curriculum, and limited access to sufficient materials to address the needs of every child simultaneously
Namukasa et al. (2023a, 2023b)	Peripheral	Primary Education	Design-based Research	Mixed-methods	Questionnaire Notes Photographs	Positive impact and enhancement of knowledge, skills, and confidence to teach mathematics using Maker practices

Table 4 (continued)

Author(s)/Year	Style	Educational Stage	Practical Integration Proposal	Evaluation	Instruments	Results
Ramey and Stevens (2023)	Collaborative	Primary and Secondary Education	FUSE Studios Program	Qualitative	Semi-Structured Interview	Teachers face several dilemmas when transitioning to a facilitator role in STEAM learning. These challenges arise from tensions or contradictions inherent in the FUSE Studios model and between FUSE and the traditional classroom structure
Douglass (2023)	Subordinate	Primary Education	Insertion on a Maker-space	Qualitative	Observations Pre- and post-maker reflectione Interview through Google forms	The participants expressed positivity, creativity, and joy in their perspectives on teaching their future students. The Maker Lab provided the space and learning experiences to expand the participants' identities related to their future teaching and interactions with STEM content applications
Fields and Kafai (2023)	Collaborative	Secondary Education	e-Textiles Curricular Unit	Qualitative	Semi-Structured Interview	They highlight the connective practices teachers employ inside and outside the classroom to promote equity and access in computer science education

Table 4 (continued)

Author(s)/Year	Style	Educational Stage	Practical Integration Proposal	Evaluation	Instruments	Results
Perez et al. (2023)	Collaborative	Preschool	Immersive Literary Environments (ILEs) with augmented reality	Quantitative	Validated instrument COMPASS-AR	A high level of teaching, socio-collaborative, and creative competencies was observed. The mastery of technological tools was high. Digital competence reached a medium–high level due to the limited integration of developed resources
Namukasa et al. (2023a, 2023b)	Collaborative	Primary and Secondary Education	Iterative design process; Project-based Learning	Qualitative	Observations Interviews Questionnaire	Professional development focused on Maker education positively impacted confidence, interest, and teaching practices related to technology and STEM instruction
Gravel and Puckett (2023)	Subordinate	Secondary Education	Workshop Projects Engineering Design Problem solving	Qualitative	Field Notes Observations Recordings Videos Interviews	Teachers show willingness to adopt Maker education, but they need support, adequate resources, and professional development. The study highlights the importance of flexible schedules, a supportive school culture, and policies aligned with Maker education objectives

Table 4 (continued)

Author(s)/Year	Style	Educational Stage	Practical Integration Proposal	Evaluation	Instruments	Results
Walan and Gericke (2023)	Subordinate	Primary and Secondary Education	Continuous-Professional-Development Program (CPD)	Qualitative	Semi-Structured Interview	Teachers identified a clear alignment between makerspace activities and curriculum objectives in STEM subjects. There was an increase in engagement and motivation during the activities. The activities, including programming, encouraged experimentation and innovative solutions
Hughes et al. (2022)	Peripheral	Preschool Primary Education	Experiences in Maker Teaching Practices	Qualitative	Semi-Structured Interview	They identified several overlapping characteristics that support teachers'transition to Maker educators, including alignment with Maker values and proficiency in interdisciplinary program planning
An et al. (2022)	Collaborative	Preschool Primary and Secondary Education	TMSR Model (Thinkering, Making, Sharing, Reflecting)	Mixed-methods	Reflective essays Thematic analysis	K-12 teachers'reflections indicated that collaboration and the integration of the arts facilitated focused, creative, and inclusive learning, expanding access to educational resources and promoting a collaborative learning environment

Table 4 (continued)

Author(s)/Year	Style	Educational Stage	Practical Integration Proposal	Evaluation	Instruments	Results
Shin et al. (2021)	Collaborative	Primary Education	Community-Based Learning in STEM (CSTEM)	Qualitative	Interviews Artifacts Observation	The findings show that future teachers used their knowledge to make creation practices more relevant to them, act as specialists, promote collaborative learning, and contribute creative ideas to creation projects
Hughes et al. (2021)	Collaborative	Primary and Secondary Education	Design-Based Research	Qualitative	Semi-Structured Interview Field Notes	The evaluation highlights that the approach effectively prepared teachers to integrate Maker education into STEAM teaching. The authors suggest an active, collaborative, continuous, and supportive approach to promote sustainable teaching practices
Shively. et al. (2021)	Collaborative	Primary Education	Workshop Educational game	Qualitative	Tutor Notes Lesson Plans Reflective Journal	The study concludes that non-traditional environments, such as Maker spaces, can promote essential skills and attitudes in novice educators, encouraging a growth mindset and the appreciation of planning and learning from mistakes

Table 4 (continued)

Author(s)/Year	Style	Educational Stage	Practical Integration Proposal	Evaluation	Instruments	Results
Lummis et al. (2021)	Subordinate	Secondary Education	Faraday Project	Qualitative	Open Questions Diaries Records	The study highlights the aspirations of the Faraday Project to promote innovative STEM education and an education system focused on testing. While teachers valued inquiry-based learning, system limitations, especially in high school, hindered the full adoption of these approaches
Douglass and Verma (2021)	Peripheral	Primary Education	No	Qualitative	Written self-reflections, written reflections of classes Semi-Structured Interview	No
Quigley et al. (2020)	Peripheral	Primary Education	STEAM unit focused on a fishing scenario	Qualitative	Heading Unit Plans Reflections Field Notes	The study highlights the interconnection of STEAM principles and the importance of continuous support for teachers to translate these concepts into practice

Table 4 (continued)

Author(s)/Year	Style	Educational Stage	Practical Integration Proposal	Evaluation	Instruments	Results
Blackley et al. (2017)	Collaborative	Primary Education	Reflexive Identity Formation Model	Qualitative	Focus Group Interview Observations and Notes	The STEM Makerspace project, along with the Reflective Identity Training Model, positively impacted the confidence and competence of pre-service teachers in STEM education

According to the analysis of the parameters shown in Table 4, the practical proposals presented in the reviewed studies reflect the diversity of strategies for integrating the Maker model into STE(A)M education. These initiatives differ in sophistication, scope, and pedagogical objectives, ranging from more traditional approaches, such as Project-Based Learning (Halliburton et al., 2024; Kay & Buxton, 2024), to the adoption of innovative technologies, like the use of immersive literary environments with augmented reality by Perez et al. (2023), and structured programs, such as the FUSE Studios program by Ramey and Stevens (2023), which promotes interactive STEAM learning.

Regarding the type of evaluation, most of the studies employed qualitative methods, such as semi-structured interviews, field notes, and observations, highlighting the focus on understanding experiences and pedagogical practices in a detailed and descriptive manner. However, some studies adopt mixed or quantitative approaches, using questionnaires and validated instruments, such as COMPASS-AR, to incorporate systematic and statistical analyses when necessary. The evaluations primarily focus on measuring changes in aspects such as confidence, pedagogical practices, knowledge, and technology integration, emphasizing the positive impact in Maker and STE(A)M teaching contexts.

Various methods are observed regarding the instruments used to assess the proposals. The most common are interviews, especially semi-structured ones, which aim to explore participants'opinions and experiences, and questionnaires, which allow standardized data collection. Observations and notes are frequently applied to analyze behaviors and contexts in real-time, while artifacts and photographs document or explore interactions with technologies and environments. Additionally, validated instruments, such as COMPASS-AR, are employed to ensure the reliability and validity of measurements.

According to the data presented in Table 4, the results of the practical proposals for integrating STEAM education and the Maker model highlight positive impacts, especially in the development of confidence and skills, and the increased interest in innovative pedagogical practices such as design engineering, augmented reality, project-based learning, and e-Textiles projects.

Halliburton et al. (2024) highlighted the improvement in teachers'confidence in using equipment and adopting Maker practices, providing a more hands-on and technological approach to teaching. Namukasa et al., (2023a, b) emphasized the increase in teachers'knowledge and skills in STEM areas by applying Maker practices, which facilitated a more dynamic and interactive approach to teaching these subjects. The study by Hughes et al. (2021) contributed to the teacher preparation in integrating Maker practices within the STEAM context, expanding the pedagogical vision, and enabling a more holistic and innovative approach to teaching. This study demonstrated how the integration of STEAM education and Maker practices can transform teacher training, enhancing essential skills for modern and interdisciplinary teaching.

These studies also pointed out significant challenges for effectively implementing Maker practices integrated with STE(A)M education. The work of Xiang et al. (2023) highlighted difficulties, such as insufficient time in the curriculum and limited access to materials that hinder the complete application of these approaches. Gravel and Puckett (2023) emphasized the need for continuous support, flexible schedules, and the alignment of educational policies to make Maker education viable in schools. Lummis et al. (2021) reinforced the structural limitations of education systems focused on testing, which restricts the adoption of more open and creative investigative methodologies. Furthermore, several studies highlighted the importance of ongoing professional development, which pointed out that continuous support and appropriate training are essential for the success of innovative pedagogical practices. Walan and Gericke (2023)

Table 5 Description of the styles based on the characteristics mobilized in the integration

Authors/year	Style	Competencies and abilities mobilized in integrating the STEAM education with the Maker model	STE(A)M disciplines that stand out
Halliburton et al. (2024)	Subordinate	Design and Production Skills; Technological Skills; Material Knowledge and Handling; Problem Solving; Critical Thinking; Creativity and Innovation; Collaboration	Technology and Engineering
Kay and Buxton (2024)	Collaborative	Design and Production skills; Technological skills; Problem-Solving; Creativity and Innovation; Collaboration	Science and Technology
Xiang et al. (2023)	Peripheral	Engineering Design Process; Problem-Solving; Communication; Cognitive Experiences; Practical Skills	Technology and Engineering
Namukasa et al. (2023a, 2023b)	Peripheral	Experimentation; Practical Activities; Problem Solving; Critical Thinking; Computational Thinking; Collaboration; Interdisciplinary Thinking	Technology and Mathematics
Ramey and Stevens (2023)	Collaborative	Student-Centered Learning; Problem Solving; Digital Literacy; Computational Thinking; Collaboration; Creativity; Innovation	Science, Technology, Engineering, Arts, and Mathematics
Douglass (2023)	Subordinate	Problem-Solving; Critical Thinking; Technological Tools; Collaboration and Communication; Innovation; Creativity; Mathematical Thinking; Technological Skills	Technology and Engineering
Fields and Kafai (2023)	Collaborative	Technological Skills; Problem-Solving; Collaboration and Communication; Creativity; Practical Skills	Technology
Perez et al. (2023)	Collaborative	Technological Skills; Creativity; Problem Solving; Practical Skills; Interdisciplinary Thinking	Art and Technology
Namukasa et al. (2023a, 2023b)	Collaborative	Technology Skills; Interdisciplinary Thinking; Tinkering; Experimentation; Iterative Design; Integrating STEM Disciplines; Real-World Applications; Collaboration and Communication	Science, Technology, Engineering, and Mathematics
Gravel and Puckett (2023)	Subordinate	Practical Skills; Technological Skills; Problem-Solving; Interdisciplinary Thinking	Technology and Engineering
Walan and Gericke (2023)	Subordinate	Collaboration and Communication; Creativity; Digital Competence; Technical Skills; Problem-Solving; Critical Thinking	Science, Mathematics, and Technology
Hughes et al. (2022)	Peripheral	Pedagogical Flexibility; Assessment Practices; Critical Thinking; Innovation; Problem Solving; Collaboration and Communication; Creativity	Science, Technology, Engineering, and Mathematics

Table 5 (continued)

Authors/year	Style	Competencies and abilities mobilized in integrating the STEAM education with the Maker model	STE(A)M disciplines that stand out
An et al. (2022)	Collaborative	Technical Skills; Design Skills; Problem-Solving; Arts and Music Literacy; Collaboration and Communication; Creativity; Critical Thinking	Technology, Engineering, and Arts
Shin et al. (2021)	Collaborative	Technical Skills; Problem Solving; Collaboration and Communication; Creativity; Critical Thinking; Inclusive Pedagogy	Science, Engineering, and Technology
Hughes et al. (2021)	Collaborative	Collaboration and Communication; Problem-Solving; Technical Skills; Creativity; Critical Thinking; Technology and Programming Skills	Technology and Engineering
Shively. et al. (2021)	Collaborative	Planning; Design Thinking; Collaboration and Communication; Problem Solving	Science, Engineering, and Technology
Lummis et al. (2021)	Subordinate	Experimentation; Problem-Solving; Technical skills; Cognitive Skills; Collaboration and Communication	Science
Douglass and Verma (2021)	Peripheral	Student-Centered Approaches; Design Thinking; Collaboration and Communication; Problem-Solving	Science and Mathematics
Quigley et al. (2020)	Peripheral	Inquiry-Based Learning; Problem-Solving; Design Thinking; Collaboration and Communication; Creative Thinking	Science, Engineering, and Mathematics
Blackley et al. (2017)	Collaborative	Problem-Solving; Design Thinking; Experimentation	Technology and Engineering

highlighted that professional development increases teachers'engagement and motivation, while An et al. (2022) demonstrated that collaboration and integrating arts facilitate more creative and inclusive learning. Perez et al. (2023) showed how technological integration can enhance teachers'didactic and collaborative skills, making them better equipped to face contemporary educational challenges.

In the context of the various styles of integrating STEAM education and the Maker model, the analysis of the studies reveals a predominance of the collaborative style, identified in 10 studies, followed by the subordinate style in 6 studies and the peripheral style in 4, as presented in Tables 4 and 5. In Table 5, we highlight the competencies and skills mobilized in the integration of STE(A)M education with the Maker model and the subjects that stand out in STE(A)M education for each study.

The collaborative style is defined by a balanced integration of the Maker model with STE(A)M education, offering students an in-depth, hands-on, interdisciplinary learning experience. Studies by An et al. (2022), Kay and Buxton (2023), and Perez et al. (2023) highlight the importance of interaction and active learning using project-based approaches and iterative models. An example is the TMSR (Thinkering, Making, Sharing, Reflecting) model, analyzed by An et al. (2022), which integrates the Maker model with arts and coding, promoting a holistic experience. The authors emphasize the advantages of this approach, arguing that it allows students to deepen their understanding in an integrated and hands-on way, both in the Maker context and across STEAM disciplines. This type of integration encourages creativity, critical thinking, and the development of interdisciplinary skills, which are essential for contemporary education.

Perez et al. (2023) also emphasize the development of holistic teaching competencies, including digital, creative, and socio-collaborative skills. In addition, Shin et al. (2021) highlighted how Maker projects allowed teachers to connect personal and academic knowledge, thereby promoting meaningful learning. Meanwhile, Hughes et al. (2021) demonstrated that investigative Maker practices, such as robotics and 3D printing, stimulated creativity and problem-solving among students while also preparing teachers to integrate Maker education into STEAM teaching sustainably.

Finally, the study by Blackley et al. (2017) suggests that the Maker model serves as a platform to apply and deepen STEM education knowledge. The Makerspace in STEM (MIS) project uses the Makerspace concept to involve pre-service teachers and students in a hands-on, project-based learning experience that integrates skills and knowledge from science, technology, engineering, and mathematics. It also emphasizes the development of 21st-century learning skills, such as collaboration, communication, creativity, and problem-solving, which are essential to both Maker education and STEM education.

The peripheral style, in turn, is characterized by complementing STE(A)M educational practices with the Maker model without making it the focus of the interventions. Quigley et al. (2020) showed that concrete issues, such as sustainability, facilitated interdisciplinary learning; however, the results varied according to the educational level. These authors also emphasized the need for continuous support to transform STEAM concepts into feasible practices. Although elements of Maker, such as design thinking and technology, are mentioned, the focus of learning remains on STEAM disciplines, and the Maker model acts to enrich pedagogical practice but not as a central element.

Studies such as those by Xiang et al. (2023) and Namukasa et al. (2023a, b) also fit within this style, emphasizing reflective practice and exploring innovative approaches in traditionally rigid educational systems. For Xiang et al. (2023), the Maker model is integrated in a substantial but still secondary manner, functioning as a complement to the core content teaching. According to the authors, the Maker model reinforces the learning of

STEM content yet maintains an auxiliary role. The study by Douglas and Verma (2021) highlights that informal makerspaces complement STEM curricula, although their impacts have not been formally evaluated. This suggests that makerspace experiences, while important, are not intended to replace or fully drive the main STEM curriculum, aligning with the peripheral integration style.

Finally, in the subordinate style, the Maker model is employed as a complementary resource aimed at supporting and strengthening the learning of specific content often associated with STE(A)M education. The impacts, although targeted, face challenges due to a lack of pedagogical strategies for integration. Studies such as those by Halliburton et al. (2024) and Douglass (2023) emphasize direct instruction and teachers'technical skills development, focusing on controlled experiences, such as workshops and STEM labs, which provide structured support to promote confidence and content mastery. Walan and Gericke (2023) highlight the alignment between Maker activities and curriculum objectives. However, these studies also highlight the need for continuous support to ensure the effective implementation of these practices. Gravel and Puckett (2023) corroborate this understanding by demonstrating that Maker projects helped translate STEM concepts into physical artifacts, although they required constant teacher adaptations. Finally, Lummis et al. (2021) emphasize using innovative environments and investigative practices to strengthen STEM learning, focusing on assessments and university preparation. This approach, centered on the disciplines, limits the adoption of a more open form of learning characteristic of the Maker style. Although it incorporates aspects of innovation, the Maker model serves a secondary role, acting as a supportive tool to enhance STEM education teaching.

Another parameter analyzed in the selected articles is the competencies and skills mobilized to integrate STE(A)M education and the Maker model. The 21st-century competencies identified by the Global Partnership for Education (2020) were adopted to classify the skills developed through STEM interventions in the reviewed publications. The data highlight a varied emphasis on these essential competencies, reflecting the diversity of approaches to developing critical skills. Table 6 presents the number of competencies and skills of the emerging styles in the selected papers. The scope of competencies reflects a comprehensive view of student development, including technical, practical, cognitive, and socio-emotional skills.

Table 6 Quantities of competencies and skills from the emerging styles

Skills and abilities	Quantity	Skills and abilities	Quantity
Problem-Solving	19	Interdisciplinary Thinking	5
Critical Thinking	8	Mathematical Thinking	2
Creativity and Innovation	6	Iterative Design	1
Collaboration and Communication	16	Technical Skills	5
Technological Skills	5	Experimentation	4
Design Skills	2	Design Thinking	3
Engineering Design Process	1	Mathematical Thinking	2
Cognitive Experiences	1	Planning	1
Practical Skills	4	Computational Thinking	2
Knowledge and Handling of Materials	1	Real-World Applications	1
Pedagogical Flexibility	1	Inclusive Pedagogy	1
Inquiry-Based Learning	1	Arts and Music Literacy	1

The analysis highlights that the most recurring competencies and skills in STEAM integration approaches and the Maker model are problem-solving, creativity, critical thinking, and collaboration and communication. These essential competencies and skills serve as a foundation for promoting innovative, collaborative educational practices aligned with the demands of the twenty-first century (Abina et al., 2024; Ortiz-Revilla et al., 2023; Ruiz-Rojas et al., 2024). Technical and technological competencies and skills also stand out, reflecting the importance of specific tools and knowledge needed to solve problems and develop projects (Kangas et al., 2022). Additionally, skills related to critical and interdisciplinary thinking, as well as experimentation, demonstrate a commitment to more hands-on and investigative learning approach.

Problem-solving is a constant in most studies, exemplified by Halliburton et al. (2024) and Shively et al. (2021), highlighting its central importance in STEAM education. Creativity, in turn, is emphasized in works by Fields and Kafai (2023) and Perez et al. (2023), deemed essential, especially in hands-on and interdisciplinary activities. Technical and technological skills receive attention in studies like those by Douglass (2023) and Namukasa et al., (2023a, b), which directly relate to engineering practices and technological tools. This overview suggests that STEAM and Maker initiatives foster cognitive and technical development and enhance socio-emotional and collaborative skills. Consequently, their ability to transform education across different levels becomes clear, suggesting a hopeful direction for modern education.

The STE(A)M discipline integration analysis indicates that the technical-scientific core is a predominant focus in STE(A)M education integrated with the Maker model. The studies highlight that technology and engineering serve as central pillars in the analyzed projects, as indicated by Halliburton et al. (2024), Xiang et al. (2023), and Fields and Kafai (2023). Additionally, science and mathematics hold significant relevance, especially in investigative and problem-solving approaches, as seen by Ramey and Stevens (2023) and Quigley et al. (2020).

The inclusion of the arts, highlighted by An et al. (2022) and Perez et al. (2023), underscores the significance of creativity and artistic literacy in interdisciplinary contexts. This disciplinary integration emphasizes the balance between technical, practical, and creative skills, as reinforced by Namukasa et al. (2023a, b), who identified interdisciplinary thinking as a central element in their practices. When present, the inclusion of the arts is associated with fostering creativity and promoting artistic or musical literacy. Additionally, there is a clear emphasis on interdisciplinarity, with the frequent combination of disciplines to reflect real-world applications and promote collaborative learning.

Conclusions

This systematic review aimed to analyze educational proposals that promote the integration of STEAM education and the Maker model in the context of teacher training, and the main challenges and strategies identified in the literature to facilitate this integration.

The analysis revealed that these approaches have played a significant role in developing teaching competencies, fostering innovative pedagogical practices, and interdisciplinarity. Some studies indicate that integrating the Maker model with learning strategies in teacher training has gained increasing prominence in school and extracurricular contexts (Benton et al., 2017; Kafai et al., 2020; Ogle et al., 2017). This finding reinforces our research by highlighting the relevance and applicability of this model in teacher education, particularly in promoting more dynamic and creative pedagogical practices. The practical proposals presented have demonstrated the potential of the Maker model as a transformative tool in STE(A)M education. Each approach, from Project-Based Learning to technological innovations, offers pedagogical practices that suits various contexts. However, successful implementation requires alignment with traditional curricula, institutional support, and continuous teacher training to overcome operational challenges and enhance the positive impact of these practices.

One of the key aspects of this analysis was the identification of different integration styles of the Maker model present in the examined proposals. The studies highlighted how various pedagogical approaches—subordinate, peripheral, and collaborative—address different aspects of teaching practice. The subordinate style focuses on developing technological skills (Douglass, 2023; Gravel & Puckett, 2023), while the peripheral style emphasizes experimentation (Lummis et al., 2021; Namukasa et al., 2023a, 2023b). The collaborative style, in turn, stands out for fostering dynamic and inclusive learning environments, driving significant transformations in interdisciplinary educational practices (Namukasa et al., 2023a, 2023b; Pérez et al., 2023; Namukasa et al., 2023a, 2023b). This diversity of styles and strategies highlights the need to adapt approaches to the specificities of teachers and educational contexts, particularly regarding the advancement of Maker and STE(A)M practices.

In the collaborative style, integrating the Maker model has been shown to provide students with a deeper, hands-on, and interdisciplinary learning experience (Kay & Buxton, 2023; Namukasa et al., 2023a, 2023b; Pérez et al., 2023). Therefore, its inclusion in teacher training is particularly relevant, as it promotes pedagogical innovation and prepares future educators to implement student-centered teaching practices. We identified several studies in which the collaborative integration style can positively enhance the integration of the Maker model, connecting concepts, objectives, and competencies from both Maker practices and other STEAM areas, as noted in the study by Sanz-Camarero et al. (2023a, 2023b) regarding the arts, which further highlights the relevance of this style in teacher training. Given the benefits of this style, its application in teacher training is especially relevant, as it promotes pedagogical innovation and the development of essential practical skills for contemporary teaching.

However, it is important to highlight that, despite the positive results reported in the studies, our research identified significant limitations — in particular, the small number of pedagogical proposals evaluated and the absence long-term analyses of their current impact on student learning. In addition, we observed a limited number of studies, only 10, that explore the integration of the STEAM approach with the collaborative Maker model, revealing an important gap in the literature and reinforcing the relevance of this study. This may affect the generalization of the results and the full understanding of the impact of the Maker model in different educational contexts. Regarding our research, we highlight the need to expand the analysis to other databases with larger and more diverse samples to minimize the bias of the results and interpretations presented here.

Finally, this research aimed to contribute to this educational model by analyzing proposals for integrating STE(A)M education with the Maker model in teacher training. The findings of this study provide initial evidence that educational proposals based on STE(A)M approaches may be a promising strategy to promote the integration of STE(A)M education and the Maker model in the context of teacher training, particularly by broadening high-quality learning opportunities for resource-poor communities.

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Declarations

Competing interest The authors declare that there is no known competing and financial interest to declare that are relevant to the content of this article.

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