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RESEARCH PERSPECTIVES ON TEACHER TRAINING IN THE STEAM APPROACH: TRENDS, CHALLENGES, AND RECOMMENDATIONS

William Orlando Álvarez Araque[1*], Hilda Lucia Jiménez Orozco[2], Marcos Daniel Rodríguez Pinzón[3]

[1]Docente de la Universidad Pedagógica y Tecnológica de Colombia, Integrante del Grupo de Investigación e Innovación y Desarrollo Productivo – GRINDEP. SIMILES E-mail: William.alvarez01@uptc.edu.co. ORCID: https://orcid.org/0000-0002-1955-3815
[2]Docente de la Universidad Pedagógica y Tecnológica de Colombia, Directora del Grupo de Investigación e Innovación y Desarrollo Productivo – GRINDEP. E-mail: hilda.jimenez@uptc.edu.co. ORCID: https://orcid.org/0000-0001-9316-9136
[3]Universidad pedagógica y Tecnológica de Colombia, Grupo de Investigación e Innovación y Desarrollo Productivo – GRINDEP. E-mail: marcos.rodriguez@uptc.edu.co
ORCID: https://orcid.org/0009-0001-7180-7333

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Corresponding Author: William Orlando Álvarez Araque (william.alvarez01@uptc.edu.co)

ABSTRACT

The implementation of STEAM education in the classroom poses challenges, and undoubtedly one of the most significant is related to the lack of preparation among educators. Some teachers do not have the necessary skills to carry out educational proposals involving interdisciplinary learning. In this regard, the purpose of this qualitative, descriptive, review-based study was to conduct a bibliographic analysis of STEAM teacher training. Unlike previous reviews, the results identify three emerging trends: the need for ongoing teacher training to synchronously integrate disciplinary, pedagogical, and technological knowledge; the need to strengthen skills for working in the classroom in interdisciplinary collaborations and to be able to integrate active methodologies specific to the digital context. The results presented allow us to conclude that concrete guidelines should be formulated so that those responsible for educational policies and teacher training centers can design more focused strategies to achieve a contextualized and sustainable implementation of STEAM teaching in school practice.

KEYWORDS: STEAM Education, Innovative Teaching, Teacher Training.

1. INTRODUCTION

Currently, educational systems, faced with the new proposal to prepare students for a new and complex world in which technology is increasingly present, must embrace STEAM (Science, Technology, Engineering, Art and Mathematics) education, which contributes to the construction of critical thinking, problem solving, creativity and interdisciplinary learning. In this regard, Zakaria and Osman (2024) stress that the STEAM approach is not only a driver of innovation, but also fosters equity and inclusion in the classroom, but its implementation depends on the role of teachers.

Despite the fact that the STEAM approach has been positioning itself in the educational agendas of several countries, there are still many teachers who do not have the necessary skills to develop it in a meaningful way. As Ishmetova (2025) argues, the lack of specific training in integrated methodologies, as well as in the pedagogical use of technology limit the potential for transformation of the STEAM approach in school environments, therefore, reflecting on how teachers are being trained is essential to move towards a more contextualized, innovative education in line with the demands of the 21st century.

In the last decade, some studies have paid attention to the need to prepare teachers to appropriate the STEAM approach from a pedagogical and didactic perspective. An example of this is the research by Leoste et al. (2020), which indicates that teacher training should transcend the domain of the discipline to incorporate active strategies, critical thinking and digital competencies; for its part, the study by Anisimova et al. (2020) highlights how initial and continuous training in STEAM remains fragmented and, in many aspects, poorly contextualized with the school reality.

Despite the growing boom in scientific interest in this line of research, there are still important gaps. Little literature accompanies the approach to systematize which are the most appropriate training trends or to understand what are the challenges that teachers encounter when applying the STEAM approach in the classroom. Likewise, it is necessary to have a critical look at how training programs are being designed and what kind of accompaniment and support educators need for the implementation of this interdisciplinary educational approach. This panorama highlights the need for a systematic review to synthesize existing knowledge and guide future training actions.

The central problem of this study lies in the poor preparation of teachers in the implementation of the STEAM approach to put it into practice in a correct way in the school environment, which is due, among other things, to their difficulty in achieving the interrelation of content through an interdisciplinary approach, in their scarce use of technologies in a pedagogical way and in their difficulty in proposing critical thinking in the classroom. Given the growing demand for a more innovative education that is connected to reality, it is worrying that there are teachers who do not have the tools to take on this challenge.

Initial teacher training in the STEAM approach has limitations that hinder its effective incorporation into educational contexts. The limitations identified in the academic literature are as follows: lack of pedagogical frameworks that are integrative and help educators connect the disciplines of the STEAM approach; lack of digital literacy skills that enable the use of emerging technologies; and insufficient training to formulate interdisciplinary teaching proposals. These shortcomings condition the qualities that teachers must have when addressing the educational, scientific, and technological requirements of today's education.

Therefore, this systematic review aims to answer key questions such as: What are the main trends in initial teacher training in STEAM? What challenges do teachers face when implementing this approach? What recommendations does the literature offer to improve teacher preparation in this field?

Exploring teacher preparation in STEAM is fundamental, given that the success of its implementation is determined, to a large extent, by the teacher's preparation and willingness. In this sense, Boice et al. (2021) argue that adopting innovative pedagogical practices requires not only technical knowledge, but also a change of mindset towards collaborative and interdisciplinary. Without adequate preparation, the STEAM approach may run the risk of being considered a set of isolated activities with no impact on student learning.

From this perspective, this study contributes value by systematizing the existing evidence on STEAM teacher training. In this way, the progress achieved, the obstacles encountered and the proposals for improvement needed to address this type of training can be substantiated. The results obtained will help to guide the design of more integrated, contextualized and sustainable training programs that empower teachers to develop meaningful learning experiences in the digital era.

The objective of the study is to analyze the most recent scientific literature regarding teacher training in the practice of STEAM education; and thus be able

to identify both research trends, guiding recommendations for future educational practices and policies, identifying the main obstacles faced by teachers when implementing this approach in their pedagogical practice and, likewise, to propose recommendations that strengthen both initial training and continuous updating of teachers in diverse educational contexts.

1.1. Theoretical References

In this section, concepts related to STEAM education in the classroom are analyzed, considering three key elements; firstly, the theoretical bases that argue this educational proposal are presented, inquiring about its evolution and pedagogical principles; secondly, the pedagogical strategies that have recently been discussed and that have shown effectiveness in its implementation are reviewed, emphasizing active methodologies and technology; finally, the effects that the STEAM approach has on student learning are analyzed.

1.2. Theoretical Foundations of STEAM Education

STEAM education is presented as an alternative to the need to modify traditional teaching plans, promoting unified learning that integrates different disciplines. Authors such as (Oanh and Dang, 2025) show that this educational proposal was born with the intention of developing 21st century competencies, such as critical thinking, creativity or problem solving (Suryaningsih et al., 2024). Throughout the literature review, it is concluded that the evolution of the STEAM approach itself has been determined by the need to innovate education in order to obtain new didactic strategies for the integration of knowledge in multiple disciplines.

Historically, STEM (Science, Technology, Engineering and Mathematics) education founded this approach that emphasized teaching from the combination of technical and scientific areas in order to respond to emerging problems in the digital era, but recent studies show that the inclusion of art (A) in the original approach increased the pedagogical potential of teaching by fostering creativity, expression and innovation in learning (Lage-Gómez and Ros, 2024). For Wised and Inthanon (2024), STEAM enhances the holistic integration of knowledge, and encourages the teaching of cross-cutting skills with applications in real-world situations. Likewise, art in STEAM has evidenced that students are not only more motivated, but it also enhances their ability to solve problems in a more flexible and original way (Siwen and Rahim, 2024).

The studies analyzed show that the STEAM approach is based on key pedagogical principles, such as inquiry-based learning, interdisciplinarity or the focus on solving problems posed by reality (Núñez et al., 2025). There is support in the literature that certain strategies are important, such as project-based learning, design thinking or collaborative learning, when implementing STEAM in the classroom (Chistyakov et al., 2023). In this sense, project-based learning allows students to face real-world challenges that require them to integrate several disciplines, while design thinking makes use of experimentation and iteration in problem solving (Kee et al., 2025).

The results of different research coincide in that STEAM education represents a change of model in the way of teaching, by promoting active methodologies centered on the student; the literature review allows recognizing that this approach not only improves learning in technical and scientific areas, but also helps students to develop their skills to develop in complex environments that require a multidisciplinary approach (González et al., 2020). Therefore, it is essential to develop educational models that promote the integration of STEAM in the classroom if we want to achieve an innovative education in the 21st century.

1.3. Pedagogical Strategies for STEAM Teaching in the Classroom.

STEAM education requires strategies that guarantee its implementation in the classroom; the academic literature emphasizes that the STEAM approach is based on active methodologies that favor experiential learning, problem solving and the practice of interdisciplinarity (Mater et al., 2023); in addition, different studies have shown that these methodologies facilitate the development of communication, creativity and critical thinking in students, key qualities for success in the 21st century (Rosyida et al., 2025).

The use of technology in the teaching-learning process is another characteristic element of STEAM education. Academic literature establishes that digital tools such as programming, robotics or 3D printing, favor interdisciplinary work, as it offers the necessary spaces to experience theory (Kalaitzidou and Pachidis), studies have shown that programming in environments such as Scratch and educational robotics favor the development of logical thinking and problem solving of the student (Chevalier et al., 2020) and, in another sense, evidence shows that augmented reality and computer-based simulations also favor learning

through an immersive process of deepening one's understanding when learning scientific and mathematical phenomena (Su et al., 2022).

Regarding good practices in STEAM teaching at different levels of the educational system, different research reports positive experiences, such as Hughes et al., (2022), who present programs where art and technology are combined to facilitate innovation. Zhou et al., (2023) analyze projects where design and engineering are linked in artistic activities with the aim of developing students' creativity. The academic literature also indicates that the interrelation of educators from different areas favors the implementation of the STEAM approach in educational centers as it promotes contextualized and meaningful teaching (Boice et al., 2024).

Ultimately, the process of assessing learning in STEAM contexts can also become challenging, as this approach also brings with it multidimensional assessment tools and processes that are difficult to assess in traditional ways. Recent research has begun to offer various assessment models, such as performance-based assessment rubrics, digital portfolios, or project-based assessments (Mang et al., 2023). In this sense, the literature points out that these forms of assessment not only evaluate the knowledge that is being generated, but also take into account the development of competencies such as problem solving, teamwork or creativity (Utomo et al., 2023). In this line, the evidence is decisive and argues that the evaluation of STEAM learning globally has to contemplate not only an evaluation of the final products of each of the projects, but also has to take into account and evaluate the ways of learning, thus guaranteeing a global and formative educational proposal.

As shown in Figure 1, pedagogical strategies for STEAM teaching revolve around active methodologies, technological integration, good interdisciplinary practices, and multidimensional assessment systems. The image summarizes the significant elements that emerge from the literature review to account for the interactions between the elements of STEAM education in the educational setting.

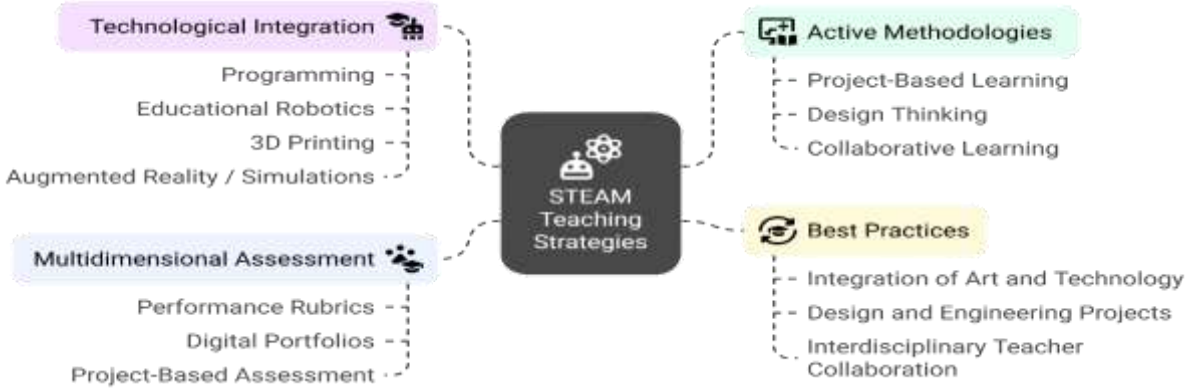

Figure 1: Conceptual Diagram of Pedagogical Strategies for STEAM Teaching in The Classroom.
Note: The figure summarizes the methodological, technological, and evaluative components identified in the literature review on the implementation of the STEAM approach.

Figure 1 shows that the successful application of the STEAM approach requires implementing a balance of active methodologies such as project-based learning, design thinking, collaborative learning, and the use of emerging technologies such as programming, robotics, and augmented reality. It also reinforces the idea of introducing good teaching practices and multidimensional assessment that focuses not only on the final result but also on the learning processes.

1.4. Impact of STEAM Education on Student Learning.

The research analyzed shows that STEAM education has a significant impact on the development of basic competencies in students. In general terms, it favors education and critical and creative thinking and problem-solving skills, competencies that are necessary in the 21st century (Casado Fernández and Checa Romero, 2023); in turn, research has shown that STEAM education promotes exploratory learning and learning based on experimentation, generating working hypotheses and original solutions in the student while reflecting on the learning process itself (Montés et al. 2022); in the same line, studies show evidence that the STEAM approach not only favors in the student the ability to solve complex problems, but also favors cognitive flexibility and the ability to transfer what has been learned to different contexts (Lin and Chang, 2025).

Another relevant effect of STEAM education is the impact it has on the interest in scientific disciplines and mathematics disciplines. There are bibliographic sources that show that traditional methodologies applied to teaching are responsible for the lack of motivation for the disciplines, but that STEAM education, by offering the integration of art together with active methodologies, makes the student find connectors between the areas and reality (Tuveri et al., 2024). There is research that shows that methodologies such as PBL or problem solving in real situations result in the student developing a greater commitment and a vision of self-efficacy in learning the areas of science and mathematics (Ekayana et al., 2025); also the academic literature argues that art in the STEAM approach has the power to decrease mathematical and scientific anxiety, and result in a more accessible, interesting and attractive way of learning these disciplines (Hughes et al., 2022).

From the perspective of the principles of equity and inclusion, STEAM education has also been welcomed as a way to increase the participation of groups that are underrepresented in STEM disciplines. In the field of research, different studies have been able to ascertain that STEAM programs make it possible to integrate women and minorities into traditionally male disciplines, based on techniques that propose interdisciplinary and creative approaches (Palid et al., 2023). Similarly, studies have also mentioned the presence of students with different learning styles to which STEAM teaching allows to cater, thanks to the fact that it combines multiple representations of knowledge from experimentation to artistic expression (Fields and Kafai, 2023). But the literature also notes the need to have educational policies that ensure that STEAM education is accessible to all students, and especially to those who come from contexts with scarce technological resources (Johnson et al., 2024).

Finally, the empirical evidence collected has shown that STEAM education has positive effects on students' academic performance. Precisely, the literature review has collected research identifying positive changes in performance specifically in mathematics, science and problem solving in the case of students who have participated in STEAM programs (Asrizal et al., 2023); it should be emphasized that studies have also shown results in favor of project-based learning or the integration of technology into teaching that, on the one hand, leads to an increase in the student's conceptual understanding and, on the other hand, improves long-term knowledge retention (Abueita et al., 2022), therefore, the integration of the STEAM approach not only supports the dissemination of basic skills, but, due to its nature closely linked to the areas of knowledge, is aimed at improving school achievement in a sustainable manner.

As shown in Figure 2, the effect of STEAM education on student learning also includes the development of key competencies, increased motivation, improved inclusion, and increased academic performance.

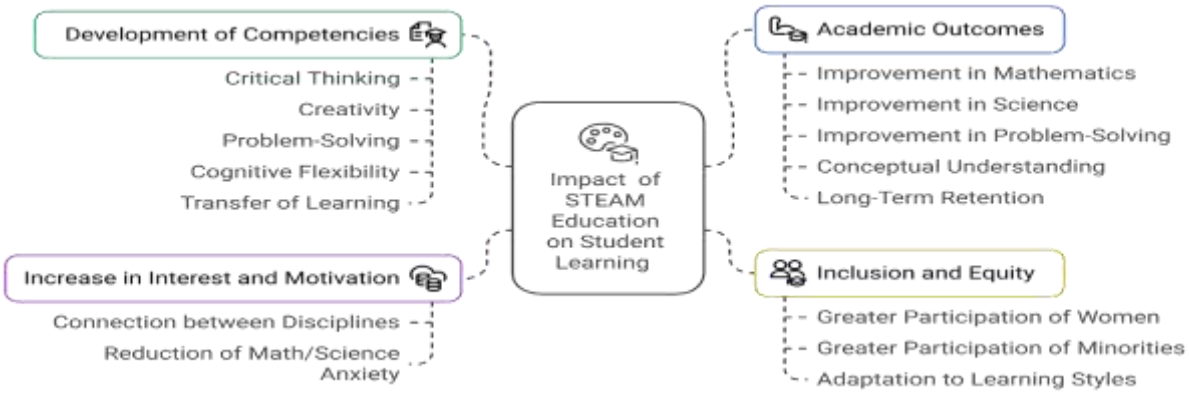

Figure 2: Conceptual Diagram of the Impact of STEAM Education on Student Learning.
Note: The Figure Summarizes the Main Effects Identified in The Literature Review, Showing Their Interrelationship and Scope in the Educational Context.

Figure 2 demonstrates that the STEAM approach not only develops within the framework of 21st-century skills education, but also increases student engagement, promotes equity, and produces sustainable improvements in school performance.

2. MATERIALS AND METHODS

This research is part of a qualitative and explanatory-descriptive approach, based on an integrative documentary review design, thus facilitating the analysis of the research visions about

teacher education in the STEAM approach, so that trends, recurrent challenges and emerging proposals from various academic sources can be identified. This choice of methodology responds to the need to be able to interpret the scientific discourse, as well as the current theoretical constructions on teacher education in educational contexts mediated by the integration of science, technology, engineering, art and mathematics.

The review strategy was based on a systematic search of academic literature in academic databases of impact such as Scopus, Web of Science, ERIC, as well as in open repositories based on academic literature such as Redalyc, Dialnet or Google Scholar. To ensure the relevance of the documents, keyword combinations were designed using Boolean operators (AND, OR), including terms such as: "teacher training", "STEAM education", "pedagogical trends", "educational innovation", "challenges in education", among others.

The selection of the documentary corpus in the STEAM approach was established under inclusion criteria: full-text academic publications were selected, published between January 2020 and January 2025, which explicitly addressed aspects related to teacher training within the STEAM approach, whether in school or university contexts; Studies focused solely on disciplinary areas without interdisciplinary and transdisciplinary articulation, non-peer-reviewed articles, and duplicate documents were excluded.

The search, selection, and refinement of information was carried out following the PRISMA protocol guidelines adapted to the research context. This allowed for the reproducible and explicit articulation of the stages of identification, screening, eligibility, and inclusion of documentary sources. First, 85 bibliographic references were retrieved from the selected databases. Subsequently, after applying the filters defined by the inclusion and exclusion criteria and reading the abstracts or full text, the set was refined to consolidate a final documentary corpus of 62 sources. The use of the PRISMA protocol ensured the traceability of the process and methodological consistency in the formation of the corpus that was analyzed.

The research process was oriented as follows: first, in phase one, the identification and recovery of academic sources was carried out using the established search criteria and method; the second phase was oriented to the qualitative analysis of the information obtained, which culminated in the identification of thematic patterns, gaps in the literature and emerging categories linked to the training of educators in the STEAM approach; finally, in the last phase of the study, practical and prospective recommendations were formulated that, based on the evidence found, can contribute to consolidate the training processes of educators.

3. RESULTS

3.1. Results First Phase: Recovery of Bibliographic Sources

The first phase of the research was aimed at identifying and retrieving academic sources related to teacher training in the STEAM approach, giving priority to those that provided an updated view of existing trends and challenges. A search strategy was developed in the main scientific databases such as: Scopus, Web of Science, ERIC, Redalayc, Dialnet and Google Scholar, formulating search equations that collected key terms such as: professional training, STEAM education, interdisciplinary teaching and teaching competencies, articulating them based on Boolean operators.

The search was articulated in a literary process that was modified as the information obtained was related to the degree of relevance and suitability of the information. The filters applied were: language (English and Spanish), type of document (peer-reviewed articles, book chapters and academic theses) and period of publication (2020-2025); duplicate works, unconsolidated gray literature, as well as literature focused only on technical aspects of STEAM without accounting for the pedagogical and formative dimension related to teachers were eliminated.

Once the documents had been purified and the analytical reading of the documents was completed, we proceeded to build a corpus of documents made up of significant articles that contributed content to the theoretical framework and the discussions. The sources were reorganized into two emerging thematic lines: A first line on trends in teacher training for STEAM education that incorporated innovative pedagogical approaches, models and designs. And a second line on the challenges in the implementation of the STEAM approach in educational practice focused on institutional, curricular and formative barriers.

The retrieval of documentary sources made it possible to build a solid and current theoretical base (see Figure 1) that shapes the main contemporary debates on teacher training in contexts of interdisciplinary teaching and educational innovation.

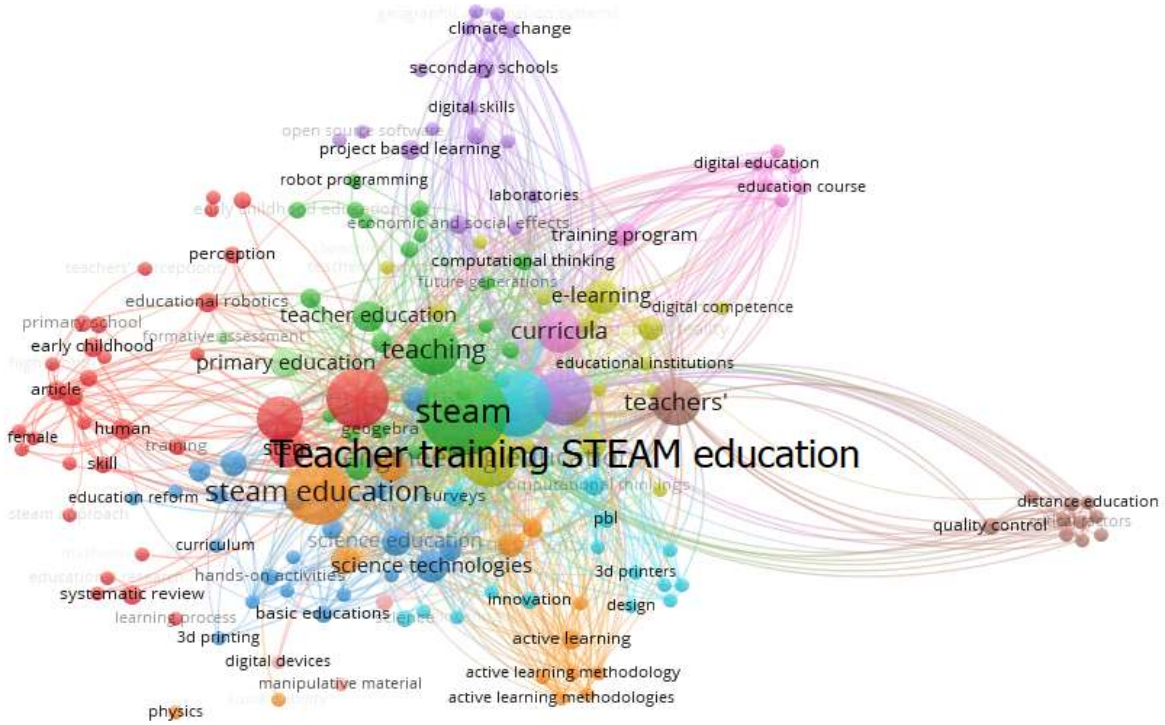

Figure 1: Bibliometric Network on Teacher Training and STEAM Education.
Note: Own Elaboration in Vosviewer Based on Scopus Records.

The bibliometric network shown in Figure 1, allows observing the main conceptual cores, as well as the existing relationships between the most recurrent terms within the scientific literature dealing with teacher education in the STEAM approach. There is evidence of a central articulation between categories such as teacher training, STEAM education, curriculum and teaching that reflect the trends taking place in current teacher training models oriented to interdisciplinary pedagogical practice. In the same way, thematic groupings are observed that point towards experiences related to digital competencies, educational institutions, distance education and project-based learning, which refer to the structural, pedagogical and technological challenges for the STEAM approach in different school environments. This visualization proposed here confirms, consequently, the two lines of analysis that are presented in the review: the formative trends that develop innovative and integrative approaches; and the challenges that must be faced to consolidate formative processes aligned with the requirements of STEAM education.

3.2. Results of the Second Phase: Analysis of Bibliographic Sources

The second phase of the research corresponds to the analysis of the bibliographic sources selected during the systematic review; a total of 62 studies published between 2020 and 2025 were reviewed, coming from searches in specialized databases such as Scopus, Web of Science and ERIC; among the inclusion criteria, it was taken into account that the studies were related to the training of educators in the STEAM approach at different educational levels.

The analysis of the different studies made it possible to identify the existence of three recurrent thematic axes that structure the most relevant findings: Trends in teacher training for STEAM education, difficulties for its implementation and integration in the classroom, and suggestions for strengthening training processes with respect to STEAM education.

3.3. Trends in Educator Training Processes in the STEAM Approach

The literature review identified that one of the main trends in teacher education for STEAM education is the conversion to interdisciplinary pedagogical models that integrate the knowledge of science, technology, engineering, art and mathematics in a practical and contextualized style. In this line, the study by Olivato and Castro Silva (2023) proposes that such integration allows combating pedagogical visions of teaching from fragmented approaches, facilitating a more meaningful learning experience. For their part, Conradty and Bogner (2020) indicate that initial

teacher education programs should provide trainee teachers with tools to be able to plan curricular activities in such a way that they can solve problems of the practical world from different disciplines.

The academic literature emphasizes that project-based learning (PBL) is one of the most promoted methodologies with respect to STEAM training, and there are studies that show that this methodology favors the development of key competencies such as critical thinking, collaboration and creativity (Chistyakov et al., 2023). From a theoretical point of view, Silva-Hormazábal and Alsina (2023) point out that PBL helps teachers to experience, in a practical way, what disciplinary integration is, which is essential when they want to put this approach into practice in the classroom with students.

The studies analyzed also show that the use of new technologies has been established as a constant in STEAM teacher training. In this sense, some studies such as Silva-Díaz et al., (2023) consider it necessary to integrate digital tools, such as programming, educational robotics, augmented reality and artificial intelligence, with the purpose of enabling learning from the technological culture that emerges from initial and continuous teacher training. Therefore, current studies affirm that new technologies equip teachers' practices to make the leap to innovation (Rahman et al, 2025).

Along the same lines, the studies analyzed coincide in highlighting that continuing education with a STEAM approach has progressed to a great extent thanks to virtuality and educational hybridization, which has allowed access to opportunities for continuing education and professional updating. Researchers such as Kohnke et al. (2024) refer that virtuality has also made it possible to organize communities of practice, collaborative online workshops or massive open courses (MOOCs) focused on interdisciplinary training. Along these lines, Zhang et al. (2024) argue that these modalities enhance teachers' self-management and encourage critical reflection on their practices.

The academic literature also indicates that interaction between teachers from different disciplinary areas is another emerging trend that stimulates the consolidation of the STEAM approach in professional training. Comparative studies show that the most effective programs develop teaching teams in interdisciplinary tasks for the collaborative design of proposals (Gülhan, 2024). Likewise, Wu (2022) highlights the value of co-creation spaces, that is, spaces where teachers jointly develop alternative pedagogical solutions.

From an international perspective, it has been found in the literature that countries with clear policies on STEAM education such as Finland, South Korea and Canada have incorporated this approach much faster in teacher training. The work of Martins and Baptista (2024) highlights those institutional orientations and collaborative arrangements between universities, schools and the technology sector are important for the development of STEAM training. But in contexts where educational policy is weak, ambiguous or imprecise, STEAM integration tends to remain an isolated initiative.

Authors such as Hwang (2022) or Li and Nagappan (2024) have pointed out how the artistic component included in the STEAM approach is becoming increasingly important in initial teacher training because art is considered useful for developing soft skills, such as empathy, creativity and communication. In this sense, the trend is towards the design of more holistic training, where art should not be considered as an aesthetic addition, but as a tool that enriches the way of understanding and trying to solve problems from a more human and integrative point of view.

Finally, some research has confirmed that the STEAM approach in teacher training is increasingly oriented towards the advancement of equitable and inclusive teaching and learning, especially in vulnerable contexts or with digital divides, in Tang's study (2025), it is shown that training programs should include strategies to ensure that technologies and the interdisciplinary approach reach all students, regardless of their socioeconomic conditions. This trend responds to the global call for a more just and transformative education, where the teacher acts as a mediator of meaningful learning opportunities for all.

3.4. Challenges in Teacher Training for the Implementation of STEAM Education

According to recent research, one of the most persistent difficulties in teacher training for the management and implementation of the STEAM approach is the lack of preparation to address the articulation of disciplinary integration. Academic studies have documented that many of the initial training programs have configured traditional curricular structures and, thus, offer little possibility of addressing real problems from a holistic perspective. Authors such as Montés et al. (2022) have argued that teachers in training receive little information on how to make pedagogical proposals between science, technology, engineering, art and mathematics, which generates uncertainty and

resistance when implementing the STEAM approach in the classroom.

Taking the evidence presented in Grewal's studies (2021), another obstacle is associated with the deficit of didactic and technological resources in educational institutions, particularly in those that are located in rural contexts or have a low budget. Along these lines, different studies have shown that the scarcity of adequate technological infrastructures or the lack of materials in line with the STEAM approach constitute a significant barrier when it comes to achieving an effective appropriation of this practice. In theoretical terms, Nyaaba et al. (2024) state that this limitation adds a burden for the teacher, who must invest time in adapting the available resources to meet the requirements of the interdisciplinary model.

A review of the studies also reveals the existence of a clear gap between educational policies linked to the STEAM approach and the reality of teacher training. In fact, in recent studies, many countries have included this approach in their respective curricular guidelines, but, at the same time, the reality shows that the integration of the STEAM approach has not been accompanied by coherent teacher training development or support for pedagogical innovation. In fact, this approach has been the subject of studies such as those of Sánchez Milara and Cortés Orduña (2024), who emphasize that the lack of public policy and teacher professional development combined with school practice generates gaps in the implementation of the approach that end up, in a certain way, generating gaps in the implementation of the approach, which ends up diluting its impact in the classroom.

It has been reported in the academic literature that in order to implement the interdisciplinary STEAM approach in the classroom, teachers' perception of their self-efficacy to teach in an interdisciplinary practice is also important. Several studies point out that a large number of educators, especially in traditional areas such as mathematics or science, are insecure about integrating elements of art or engineering, as they feel they have not mastered these areas. The results of the research by Ramey and Stevens (2023) show that this perception of weak self-efficacy negatively affects them when carrying out training processes or integrating new work methods. In this case, continuous training is a key element, but it can also be said that the literature has found evidence indicating that continuous training is fragmented, partial and poorly contextualized.

For authors such as Erawan et al. (2025), one of the most outstanding obstacles is related to the institutional culture of schools, where hierarchical organizational charts and rigid routines still exist and limit innovation. In many cases, the introduction of approaches such as STEAM by teachers is subject to resistance from their colleagues or managers, which limits their ability to transform their initiatives. In this line, STEAM education implies not only a change in work methodology, but also a cultural change that requires accompaniment, pedagogical leadership and a shared vision. Comparative studies underline those institutions that favor collaborative work and pedagogical reflection are the ones where progress can be observed on the part of teachers in appropriating the approach.

Different research has shown that school time is a difficulty that teachers must face in order to apply the STEAM approach. In most educational systems, the curriculum continues to be delimited by subjects with strict time frames, which hinders the planning and execution of interdisciplinary projects. Along these lines, Quigley et al. (2020) report that teachers make the use of non-formal or extracurricular integration strategies their only option, which requires an additional level of commitment and management. This contradiction between the curricular structure and the needs of the STEAM approach makes it urgent to rethink the time and organizational structures in elementary and middle school teaching.

On the other hand, there is evidence in the literature indicating that teachers have problems in assessing learning in the STEAM approach, given that assessment systems are used that do not adjust to disciplinary interactions and the development of transversal skills. Chen and Ding (2024) state that assessment models that focus, only, on specific contents leaving aside some competencies such as, for example, creativity, collaboration or problem solving, competencies that are the ones that best allow implementing the STEAM approach. This is a methodological challenge that must be assumed from teacher training, incorporating tools and criteria that respond to the principles of the approach.

In general terms, the review of the literature allows us to recognize that, despite the difficulties, there is a growing awareness of the need to expand teacher training so that they can respond to the demands of the 21st century. For Stevenson et al. (2024), overcoming these limitations involves integrating a more systemic vision of teacher training that incorporates not only public policies or initial and in-service training programs, but also school leadership,

educational technology and teacher collaboration networks.

3.5. Results of the Third Phase: Recommendations to Strengthen Teacher Training In STEAM

Previous studies have corroborated that one of the main lines to carry out the development of teacher training in the STEAM approach is the inclusion of training programs in a transversal and interdisciplinary character. This orientation should enable future teachers to be able to understand how various disciplines are adapted in order to respond to a specific problem by means of projects that favor critical thinking. Several lines of study have shown that effective teacher training programs include modules on collaborative work, project design and the use of educational technologies, which favors an active and practical understanding of the teaching-learning process from a STEAM perspective.

The STEAM approach has been examined in studies such as that of Camacho and Bernal (2024); and they argue that the curricular structures of initial teacher training should be rethought based on formative experiences through didactics of problems, design and experimentation. According to the literature review, the most effective models are those that articulate theory and practice from the initial stages of initial training, allowing teachers to develop competencies in terms of planning, execution and evaluation of the intervention of interdisciplinary projects. Incorporating the STEAM model from the beginning of the training can, therefore, favor a more natural and sustainable appropriation over time during professional practice.

The literature review identifies that the second aspect that is paramount for the promotion of the STEAM teacher training process is the professional development of practicing educators. According to research such as that of Spyropoulou and Kameas (2024), continuous teacher training processes must be governed by an andragogical and appropriate approach, permanently contextualized and sensitive to the real needs of teachers and their school community. It is not simply a matter of one-off training, but of providing and establishing training paths, supported by communities of practice, by guidelines and by spaces for pedagogical experimentation that favor educational innovation.

Different studies have coincided in pointing out the fact that the strengthening of teacher training, understood as the reinforcement of teaching competencies, should involve a reflective process, where educators are able to reflect on their own beliefs, practices and challenges when teaching with the STEAM approach, since this process of reflection allows them to resignify their lived experiences and give way to other pedagogical visions. The findings of Haniford et al. (2022) affirm that collective reflection spaces such as pedagogical circles or didactic laboratories allow teachers to exchange knowledge, build knowledge collaboratively and advance in disciplinary integration with more confidence.

While different studies have shown that the use of digital technologies in teacher training, in particular, has an important impact on the development of STEAM competencies, mainly those related to programming, digital design, educational robotics and simulation; different studies have also shown that they not only serve to develop the technical skills of teachers, but also allow them to generate more interactive, creative and student-centered learning environments. According to research such as that of Kostaki and Linardakis (2025), advanced digital literacy should become the central axis of teacher training focused on STEAM education.

The study by Morari (2023), argues that it is necessary to include the artistic component as an integrating axis in teacher training, since it promotes aesthetic sensitivity, innovation and divergent thinking. From the studies analyzed, it is concluded that art should not be considered a marginal element, but a vehicle to articulate the other disciplines and work on soft skills such as communication, empathy and collaboration. In this line, STEAM teacher training should ensure the balanced presence of all the letters of the acronym, avoiding those one or more disciplines are neglected.

A review of the literature shows that the strengthening of STEAM teacher training must be accompanied by the design of public policies that guarantee resources, time and institutional conditions for its development. Some studies agree that the lack of institutional support limits the possibility of pedagogical innovation, even in the case of motivated and qualified teachers. The findings of Capozzoli Kessler et al. (2024) provide a possible answer by stating that existing collaborations between universities, ministries of education, NGOs and companies in the technology sector could become a significant resource to generate spaces for training and practice of the STEAM approach in different school contexts.

Finally, as described in the study by Gunčaga et al. (2024), a link between educational research and teacher training in STEAM should be promoted. Encouraging educators to develop action research

projects, or to systematize their experiences and generate knowledge from the basis of their own realities, contributes to consolidate a reflective and innovative professional culture. This link between research and training enriches the development of educators and ensures that didactic guidelines such as those of the STEAM approach are not transitory fads, but are based on evidence, experience and educational relevance.

4. DISCUSSION

The findings of the systematic review of the academic literature show the growing consolidation of the STEAM approach as an educational paradigm necessary to respond to the important challenges posed by the challenges of education in the 21st century. However, this consolidation does not occur homogeneously in all contexts. Although the trends that mark the practical orientations in education show a positive recognition for the interdisciplinary approach to teacher training, there are still important structural, curricular and institutional gaps that hinder its effective implementation in diverse educational contexts.

One of the main trends identified is the move from fragmented disciplinary models to integrative and situated pedagogical proposals in which the integration of science, technology, engineering, art and mathematics makes sense through the resolution of real problems (Olivato and Castro Silva, 2023; Wised and Inthanon, 2024). Therefore, the integration of the STEAM approach to pedagogical practice requires the transformation of educational curricula not only to integrate content, but also to develop transversal skills, such as critical thinking, creativity and collaborative work (Rosyida et al., 2025). As stated by Conradty and Bogner (2020), project-based learning and experimental design is positioned as a key strategy to materialize the STEAM approach in teaching practice.

However, research shows that these advances coexist with a series of persistent challenges. Many initial training programs still operate under rigid structures that inhibit pedagogical experimentation and disciplinary integration (Montés et al., 2022). This is compounded by the scarcity of technological resources, particularly in rural or low-budget contexts, which limits equitable access to meaningful STEAM experiences (Nyaaba et al., 2024). This gap, as pointed out by Grewal (2021) and Johnson et al. (2024), is not only a question of infrastructure, but also of educational justice, since it accentuates inequalities in access to innovative pedagogical proposals.

On the other hand, this study also highlights the existing distance between educational policies that promote the STEAM approach and the institutional conditions for its implementation, in terms of public policy, teacher training programs or school dynamics. The lack of alignment between these issues produces what for Sánchez Milara and Cortés Orduña (2024) is a "diluted implementation", i.e., where innovation initiatives are reduced to individual actions devoid of structural accompaniment. Within this framework, teacher training emerges as a fundamental factor but also as a challenge. The references analyzed agree that training offers tend to be sporadic, fragmented and poorly contextualized (Erawan et al., 2025), which affects the sustained appropriation of the STEAM approach.

Another aspect that is also important is the perception of teachers regarding their self-efficacy in interdisciplinary teaching. The review suggests that in most cases, expecting patterns of self-efficacy and thus linking practice to self-efficacy is incorrect, especially in those teachers of fundamental or technical areas, who assume as normal insecurity to introduce artistic components, which in turn marginalizes the comprehensive teaching of the STEAM approach (Ramey and Stevens, 2023). In contrast, research such as that of Morari (2023) and Hwang (2022) underscores the transformative potential of art as an integrating axis, since it fosters soft skills for 21st century education. In this sense, it is necessary to move towards a vision of STEAM that does not hierarchize disciplines, but rather fosters an authentic, creative and balanced integration.

Evidence also highlights the strategic nature of emerging technologies in teacher training for STEAM education. Technologies such as programming, robotics and simulation allow the creation of immersive learning experiences, favoring educator motivation and student learning (Chevalier et al., 2020; Su et al., 2022), but for their effective incorporation they require training processes that favor deep digital literacy, because as Kostaki and Linardakis (2025) propose, in this way these resources would be used in a contextualized manner and not superficially.

A particularly significant finding is the need to strengthen the reflective component in teacher training, since, as Haniford et al. (2022) rightly point out, collaborative reflective spaces such as pedagogical circles or teaching laboratories allow practices to be reinterpreted, knowledge to be built collectively, and progress to be made with greater confidence towards the implementation of

interdisciplinary work. This finding is consistent with the principles of a culture of professional research, since what is put into practice is not only the reproduction of content but also the production of pedagogical knowledge from practice (Gunčaga et al., 2024).

The transferability of these findings to different educational contexts requires an analysis of the structural and cultural contexts that modulate the implementation of STEAM. In high-income settings, where there is greater access to technological resources, connectivity, and continuing education programs, the strategies that have been identified could be applied almost immediately without requiring major adaptations. In contrast, in low-income environments or those with infrastructure problems, the implementation of the STEAM approach requires more significant changes, prioritizing the strengthening of teacher training with available resources, gradually integrating accessible new technologies, and leveraging collaborative network communities to compensate for material deficiencies. This differentiation is not only key to ensuring the viability of the STEAM approach in different contexts, but also to ensuring its equity and cultural relevance.

In short, studies point to the need to create inclusive public policies that guarantee conditions for the STEAM approach to be truly implemented. As Capozzoli Kessler et al. (2024) state, in order to build transformative learning contexts, it is necessary to promote interrelationships between universities, ministries, NGOs, and the technology sector. If such coordination does not exist, the STEAM approach risks remaining at the level of discourse, without generating a real impact on teaching practices or on the training of critical, creative students who are committed to solving problems in their environment.

In general terms, the results of this research show that sustaining teacher training in the STEAM approach requires a systemic approach that articulates curriculum, training, public policy, and institutional culture. In this way, a pedagogical approach can be consolidated that is not a fad, but rather is articulated in a well-founded manner, based on evidence, experience, and educational relevance.

5. CONCLUSIONS

The research carried out has led to the conclusion that teacher training in the STEAM approach should be developed towards more inclusive pedagogical models with interdisciplinarity, project work, and problem solving as methodological and pedagogical axes, in response to the challenge of training educators who are capable of meeting current educational demands through meaningful and innovative proposals.

It is concluded that the integration of technological tools and active methodologies is established as a fundamental basis for generating teaching competencies in STEAM, but continuous training processes are required that transcend specific training and promote trajectories of updating and didactic appropriation, both in initial training and in continuous training.

One of the challenges facing educators is the existence of highly fragmented curriculum structures and institutional conditions that are not conducive to educational practices that attempt to implement the STEAM approach. A lack of resources, limited pedagogical support, and the inability to link public policy and teacher training prevent the creation of transformative educational practices.

Despite the limitations mentioned above, the review points to significant advances in training experiences that promote interdisciplinary collaboration, critical thinking, and knowledge production based on practice. These experiences also strengthen teachers' professional identity, as they identify themselves as mediators of meaningful learning and agents of educational change.

Based on the findings, it is recommended that those responsible for designing educational policies create regulatory frameworks and investment programs that ensure the effectiveness of resources and institutional conditions for the sustainable development of the implementation of the STEAM approach. Teacher training institutions are urged to develop flexible and situational curricula that integrate interdisciplinary training with digital literacy and active methodologies, as well as continuous updating pathways. For researchers, it is suggested that comparative empirical evidence be generated related to the development of STEAM competencies in different training contexts.

The gaps identified in this review represent opportunities to investigate the transferability and adaptability of the STEAM approach in contexts with different levels of infrastructure and resources, as well as the role of school culture in the adoption of interdisciplinary proposals. Similarly, they propose examining the medium- and long-term effects of teacher training programs in STEAM, incorporating mixed methodologies and longitudinal studies, with the aim of understanding not only the immediate change in teaching practice but also the sustainability of the changes and their effect on student learning.

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