A Systematic Literature Review on STEM Education for Mathematics and Science Pre-Service Teachers

Una revisión sistemática de literatura sobre la educación en STEM en la formación de futuros profesores de matemáticas y ciencias

Uma revisão sistemática da literatura sobre a educação STEM na formação de futuros professores de matemática e ciências

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Type of paper
Research reports and unpublished essays

Doi:/10.17533/udea.unipluri.348447

Cite this article:

Castrillón-Yepes, A., & Lebrun-Llano, V. (2023). A systematic literature review on STEM Education for mathematics and science pre-service teachers. *Uni-Pluriversidad, 23*(1-2), 1-20. https://doi.org/10.17533/udea.unipluri.348447

Received: 2023-05-12 / Accepted:2023-12-20

Abstract

The integration of science, technology, engineering, and mathematics (STEM) into educational systems has grown rapidly in international research. The literature reports on policies, experiences, and programs focused on interdisciplinary STEM integration around the world, as well as the challenges that the approach represents for the integration processes that teachers may undertake. Teachers, then, play a key role in the implementation of STEM Education in the school system. This systematic literature review analyzed the strategies for STEM Education of future mathematics and science teachers and the purposes for which they have been incorporated in both research and teacher education. The review considered peer-reviewed studies published in the period 2012-2021 written in Spanish, English, and Portuguese. The review followed a three-step process: planning, conducting and reporting the review. The results show the roles that STEM Education has played in teacher education, both in research and the design of preparation programs. The methodological strategies for preparing future teachers are also reported. Finally, the review provides evidence of the opportunities offered by including STEM Education approaches in early teacher education, regarding the impact on their perceptions, conceptual knowledge, self-efficacy, and future practices.

Keywords:
STEM Education, integrated STEM, interdisciplinary education, interdisciplinarity, pre-service teacher education, mathematics teacher, science teacher, literature review.

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Palabras clave:

Educación STEM, Educación STEM integrada, educación interdisciplinar, interdisciplinariedad, formación inicial del profesorado, profesor de matemáticas, profesor de ciencias, revisión de literatura.

Resumen

La integración de la ciencia, la tecnología, la ingeniería y las matemáticas (STEM) en los sistemas educativos ha crecido rápidamente en la investigación internacional. La literatura da cuenta de políticas, experiencias y programas centrados en la integración interdisciplinaria de STEM en todo el mundo, así como de los desafíos que el enfoque representa para los procesos de integración que pueden emprender los docentes. Los docentes, entonces, juegan un papel clave en la implementación de la Educación STEM en el sistema escolar. Esta revisión sistemática de la literatura analizó las estrategias para la Educación STEM de los futuros profesores de matemáticas y ciencias y los propósitos para los que han sido incorporadas tanto en la investigación como en la formación docente. La revisión consideró estudios revisados por pares publicados en el período 2012-2021 escritos en español, inglés y portugués. La revisión siguió un proceso de tres pasos: planificación, realización e informe de la revisión. Los resultados muestran los roles que la Educación STEM ha jugado en la formación docente, tanto en la investigación como en el diseño de programas de preparación. También se informa de las estrategias metodológicas para la preparación de futuros profesores. Por último, la revisión aporta evidencias de las oportunidades que ofrece la inclusión de enfoques de Educación STEM en la formación de profesores, en cuanto al impacto sobre sus percepciones, conocimientos conceptuales, autoeficacia y prácticas futuras.

Palabras Clave:

Educação STEM, educação STEM integrada, educação interdisciplinar, interdisciplinaridade, formação inicial de professores, professor de matemática, professor de ciências, revisão da literatura.

Resumo

A integração da ciência, tecnologia, engenharia e matemática (STEM) nos sistemas educacionais tem crescido rapidamente nas pesquisas internacionais. A literatura relata políticas, experiências e programas voltados para a integração interdisciplinar de STEM em todo o mundo, bem como os desafios que a abordagem representa para os processos de integração que os professores podem realizar. Os professores, portanto, desempenham um papel fundamental na implementação da educação STEM no sistema escolar. Esta revisão sistemática da literatura analisou as estratégias para a educação STEM de futuros professores de matemática e ciências e as finalidades para as quais elas foram incorporadas tanto na pesquisa quanto na formação de professores. A revisão considerou estudos revisados por pares publicados no período de 2012 a 2021, escritos em espanhol, inglês e português. A revisão seguiu um processo de três etapas: planejamento, condução e relatório da revisão. Os resultados mostram os papéis que a Educação STEM tem desempenhado na formação de professores, tanto na pesquisa quanto na elaboração de programas de preparação. As estratégias metodológicas para a preparação de futuros professores também são relatadas. Por fim, a análise fornece evidências das oportunidades oferecidas pela inclusão de abordagens da Educação STEM na formação inicial de professores, em relação ao impacto sobre suas percepções, conhecimento conceitual, autoeficácia e práticas futuras.

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1. Introduction

Current challenges of science and society require citizens to identify and solve complex problems in interdisciplinary ways (Carmona-Mesa et al., 2019). Therefore, it is essential to integrate knowledge and skills from different disciplines to analyze and address problems from a global, non-segmented perspective (Widya et al., 2019). As a response to this need, STEM Education has been embraced, aiming to establish interaction and integration of Science, Technology, Engineering, and Mathematics (Nadelson & Seifert, 2017). Achieving the effective integration of STEM areas requires facing challenges in both macro and micro curricular dimensions, specifically regarding issues such as public policy and classroom design and management. Recent studies show that teachers face several challenges while integrating STEM areas into their daily practices (Kučuk, 2021; An, 2020; Maass et al., 2019; Carmona-Mesa et al., 2019). First, the need to promote experiences and opportunities for interdisciplinary education has been reported (Kučuk, 2021; An, 2020, Castrillón-Yepes, et al., 2023); these opportunities include the presence of curricular or extra-curricular spaces that allow to establish relations between different disciplines, but also where the term can be discussed within the framework of teacher's professional education. (Castrillón-Yepes et al., 2023)

It has also been documented that teachers may lack the confidence, or the disciplinary and pedagogical knowledge needed to integrate STEM subjects (Maass et al., 2019; Margot & Kettler, 2019) or to work jointly with other teachers (Carmona-Mesa et al., 2020; Goos et al., 2023; Widya et al., 2019). These challenges may emerge from the mono-disciplinary approach that has prevailed in preparation programs (Maass et al., 2019), or from the limited availability of instructional materials and high-quality professional education (Margot & Kettler, 2019; Castrillón-Yepes et al., 2023).

To address these challenges, researchers have designed courses, strategies and teacher education programs in integrated STEM Education including project development (Carmona-Mesa et al., 2019), modeling and experimentation (Carmona-Mesa et al., 2020), collaborative learning (Akaygun & Aslan-Tutak, 2020), design-based science education (Bozkurt Altan et al., 2016), and technology-integrated STEM applications (Alan et al., 2019). Although the literature reports on tools, activities, and teacher education experiences, further research is still needed on ways to organize programs, courses, and future teacher education. Among the STEM disciplines, mathematics and science have traditionally been part of the curriculum; they are seen "as essential components of schooling, rivalled only by literacy. Hence, teachers of each face substantial political and social pressures from outside the school" (Bishop, 2008, p.49). Therefore, in this systematic literature review, we analyze strategies for STEM preparation of future mathematics and science teachers, and the purposes for which these strategies have been incorporated into both research and teacher education.

2. Background

2.1. STEM Education

Although the use of the acronym STEM has spread globally in education, there is not a homogeneous understanding of its conceptual, educational, and integrative foundations. Therefore, different interpretations, scopes, approaches, and denominations (e.g., STEM

Education, integrated STEM, integrated STEM Education, etc.) exist in the literature, hindering a unifying framework. For Aguilera and Ortiz-Revilla (2021), the diversity of denominations may be due to the varied social (e.g., academic, educational, or political) and geographical contexts in which the term is used and to a poor theoretical foundation of its definitions. Another reason is that "STEM Education research is still in an embryonic state; the field is lacking a scientific evidence base that can inform the development of theory, policy and practice" (Goos et al., 2023, p. 1199).

The literature offers four definitions of STEM Education (Aguilera & Ortiz-Revilla, 2021). The first focuses on solving problems based on mathematics and science concepts and procedures, incorporating engineering strategies and the use of technologies. The second includes approaches where both teaching and learning are explored using two or more STEM areas and/or where STEM is related to one or more school subjects. The third seeks to teach content from two or more STEM areas in real contexts considering connections between the subject and the students' daily lives. The fourth states that STEM is a meta-discipline that uses an integrated teaching approach without dividing specific STEM contents and dynamic instructional methods.

According to Nadelson and Seifert (2017), trying to have a unified STEM definition requires considering aspects such as the need for flexibility, context variability, and a range of applicability conditions. They define an integrated STEM approach as:

> The seamless amalgamation of content and concepts from multiple STEM disciplines. The integration takes place in ways such that knowledge and process of the specific STEM disciplines are considered simultaneously without regard to the discipline, but rather in the context of a problem, project, or task. Problems that require an integrated STEM approach are typically ill structured, with multiple potential solutions, and require the application of knowledge and practices from multiple STEM disciplines. (Nadelson & Seifert, 2017, p. 221)

Although the terms Integrated STEM and STEM Education have gained increasing worldwide attention, the second one is also used to mean the integration of science, technology, engineering, humanities (arts), and mathematics. However, STEAM sometimes alludes simply to the provision of limited support for each of these areas separately (Akaygun & Aslan-Tutak, 2020; Carmona-Mesa et al, 2019; 2020). In its origins, STEM was considered an approach concerned with the improvement of economic competitiveness and the promotion of the professions associated with Science, Technology, Engineering, and Mathematics (STEM), as well as with initiatives such as the recovery of security after World War II and the Cold War space race (Chesky & Wolfmeyer, 2015). Currently, with the integration of arts into its framework, there has been an interest in extrapolating STEM preliminary purposes to the development of skills related to problem solving, creativity, critical thinking, and collaborative work (An, 2020; Kanadlı, 2019; Widya et al., 2019).

The STEM experiences reported in the literature consider mono-multi-inter, and transdisciplinary levels of integration of disciplines (Vasquez et al., 2013). Incorporating all the areas that make up the acronym at the same time is not necessary, and the possible connections between areas can emerge according to the problem to be addressed. In addition, within the framework of the skills that are expected to be promoted, it is possible to consider different methodological resources that allow some degree of disciplinary integration, for example, Project Based Learning (PBL), computational thinking, scientific inquiry, mathematical modeling, and engineering design favor interdisciplinarity (Carmona-Mesa et al., 2020). They become potential elements when educational experiences are implemented under the STEM approach.

Even though there are no homogeneous terms or conceptual frameworks for STEM Education, there is a growing interest in an interdisciplinary approach that fosters a deep articulation among the disciplines that make up the acronym: Science (what exists naturally and how it is affected), Technology (modification of the environment to meet human needs and desires), Engineering (systematic and iterative approach to designing objects, processes, and systems), Mathematics (study of numbers, symbolic relationships, patterns, forms, uncertainty, and reasoning), and finally, Art (language, aesthetics, sport, history, politics, and sociology) (Yakman & Lee, 2012; Carmona-Mesa et al., 2019). In this perspective, the "A" in the acronym involves human and social development, which suggests discussions regarding how human and social areas can fit in these interdisciplinary logics (Carmona- Mesa et al., 2019).

2.2. Current Survey Studies on STEM Teacher Education

With the growing interest in STEM teacher education, numerous empirical and survey studies have emerged, contributing to the progress of this field and improving teacher education. Key topics in these surveys include teachers' knowledge, perceptions, and practices (Anita et al., 2021; Han et al., 2021; Huang et al., 2022; Margot & Kettler, 2019); and design teacher education strategies, tasks, courses, and programs (Han et al., 2021; Huang et al., 2022; Lo, 2021). Additionally, the nature of STEM research and challenges in promoting STEM Education are explored.

Researchers have focused on understanding teachers' knowledge, perceptions, and practices regarding STEM Education and its importance in education (Margot & Kettler, 2019; Huang et al., 2022). Margot and Kettler (2019) reviewed 25 papers from 2000 to 2017, revealing teachers' recognition of STEM activities' importance and their cross-curricular benefits. In the Gül and Taşar's (2020) review, it was found that research with pre-service teachers is mainly focused on implementing activities, including theoretical subjects and activities on STEM. Anita et al. (2021) reviewed 19 empirical articles, identifying dominant STEM practices for mathematics teachers, such as critical thinking, communication, collaboration, problem-solving, inquiry-based pedagogy, problem-based learning, and project-based learning, among others. Recently, Huang et al. (2022) reviewed 76 articles from 2006 to 2020, identifying knowledge foci, professional development approaches, outcome measurements, and data sources in STEM teacher professional development programs. The review concluded that research on Teacher Professional Development (TPD) has shown a central interest in pedagogical knowledge and pedagogical content knowledge, followed by an interest in technological content knowledge and Technological Pedagogical Content Knowledge (TPACK).

Another trend in STEM teacher education reviews is the focus on communities, strategies, courses, and programs for teacher education. Lo (2021) analyzed 48 studies on integrated STEM from 2015 to 2020, aiming to develop design principles for effective TPD for STEM Education integration. The findings by Lo (2021) revealed that TPD programs emphasized three elements: content knowledge, pedagogical content knowledge, and sample STEM instructional materials. Thus, the author proposes ten design principles grouped into the following seven topics: *content focus*, *use of models and modeling*, *active learning*, *collaboration*, *coaching expert support*, *feedback, and reflection*.

Huang et al. (2022) observed a trend in mixed approaches to professional development, with activities such as learning by design, learning by doing, reflective learning, and group work. For the authors, these approaches emphasize teacher participation in the process, establishing links between content and classroom practices, and encouraging collective participation in knowledge development. Characteristics and possibilities of STEM-learning communities were the focus of the review by Han et al. (2021) in which the authors analyzed 10 articles on Community of Practice in Integrated STEM Education. They report that authentic situations are a key element in STEM integration. They also point out that professional development, communication among members, and community engagement were identified as critical components of the integrated STEM Community of Practice. The study also describes the cross-disciplinary and interdisciplinary nature of these communities and recommends creating partnerships within and across Communities of Practice as a key aspect of integrated STEM Education.

Gül and Taşar (2020) examined 76 studies on research instruments in pre-service teacher education, finding that many studies used interview forms for data collection with mixed samples of teachers, justified by the need for interdisciplinary preparation. The study found mainly qualitative methodologies and, to a lesser extent, design research. Regarding the research structure, it was reported that approaches, methods, and techniques such as engineering design process, inquiry-based learning, mathematical modeling, project-based learning, and problem-based learning prevailed. Accordingly, Gül and Taşar (2020) warned about the scarce research on pre-service teachers' STEM pedagogical content knowledge, which contrasts with the marked emphasis given to this subject in in-service teacher education processes (Huang et al., 2022). Gül and Taşar (2020) point out that valid and reliable measurement tools focused on STEM are needed. This conclusion complements the advice by Huang et al. (2022), who suggest that future research should transcend the analysis of data on teachers' perceptions and generate validated and generalizable data collection instruments. Huang et al. (2022) also questioned methodological choices in research, preparation processes, and initiatives associated with initial teacher education in STEM.

Integrating STEM Education into everyday school life requires the recognition and overcoming of several difficulties. For instance, Margot and Kettler (2019) reported that teachers perceive barriers to the development of interdisciplinary programs (e.g., typical school structures, assessment, lack of support for teachers) and requested actions to improve this integration (e.g., collaboration, use of student-centered and inquiry-based instructional models). Other difficulties in the implementation of integrated STEM Education were reported by Lo (2021), for instance: pedagogical challenges (teachers' limited STEM knowledge) and structural challenges (teachers' lack of preparation time and resources).

Collectively, this body of literature provides an overview of efforts, interests, and issues in understanding and addressing STEM teacher education. Although the scope of research is broad, there is a notable interest in teachers' knowledge, mainly in technological knowledge (TPACK, e.g., Huang et al., 2022). Additionally, we did not find studies offering a classification of STEM integration methods nor of how interdisciplinarity in STEM Education is usually considered. Even though some aspects of TPD design can be extended to pre-service teacher programs, there are no automatic procedures for the design of these programs, as university courses and lessons involve variables related to context, curriculum, experience, and pre-service teacher conceptual background which may condition their experiences in STEM Education. Beyond the findings reported in the literature, it is necessary to consider other elements in the experiences and methods used in the initial preparation of mathematics and science teachers, such as the purposes of such integration, to specify theoretical and methodological foundations to adequately integrate STEM Education in future teacher education. In this sense, this systematic literature review aims to identify the roles of STEM Education in future mathematics and science teacher preparation as well as to investigate existing preparation strategies.

3. Methodology

This article presents a systematic literature review aiming to identify, analyze and interpret available information relating to a specific and delimited research question (Wohlin et al., 2012). Reviews of this type are characterized by being rigorous, structured and explicit in both the processes of information collection and analysis. In this line, the present review follows a three-step process proposed by Wohlin et al. (2012) for planning, conducting, and reporting the review. Each of these processes are presented below.

3.1 Planning the Review

Planning requires identifying the relevance of the review and recognizing the field, its background, and prior research, as described above (section 2). Based on this analysis, research questions are formulated to be systematically answered. This review is guided by the following research questions:

- RQ1: What are the research and pedagogical purposes that STEM Education addresses for pre-service mathematics and science teacher education?
- RQ2: What main strategies, methodologies and curricular designs have been used in pre-service teacher education under the STEM approach?

To answer these questions, we developed a review protocol to plan the information collection, organization, and analysis strategies of our study. The selected databases were Scopus and Eric because they offer ample international academic production. Furthermore, Eric specializes in educational topics. The search included academic production over a 10-year span between 2012 and 2021 in Spanish, English, and Portuguese. For information systematization, we considered descriptive geographical and temporal aspects, as well as information that could help answer the research questions.

Based on the suggestions of Wohlin et al. (2012), we mapped the literature using relevant terms to the review so that the initial databases request results could contribute to the construction and refinement of the search equations.

Additionally, the protocol guaranteed the quality and reliability of the selected documents, based on a two-phase process that uses Cohen's Kappa coefficient, according to Pérez et al. (2020) suggestions. The first phase guaranteed a satisfactory degree of agreement among researchers in the selection of documents using the search equations and, if necessary, the Kappa coefficient to refine inclusion and exclusion criteria. The second phase focused on sharing and reviewing the documents selected in the first phase, consolidating the final documents to be included. The application of this protocol is presented in the following subsection.

3.2 Conducting the Review

According to Wohlin et al. (2012), the execution of the protocol is realized through the review process. In line with this purpose, we delimited inclusion and exclusion criteria (Table 1) to recognize the contributions of the STEM approach in the initial preparation of mathematics and science teachers. This stage constitutes a relevant action to take the available research and limit it to articles and products directly related to the topic under study.

Table 1 Inclusion and exclusion criteria

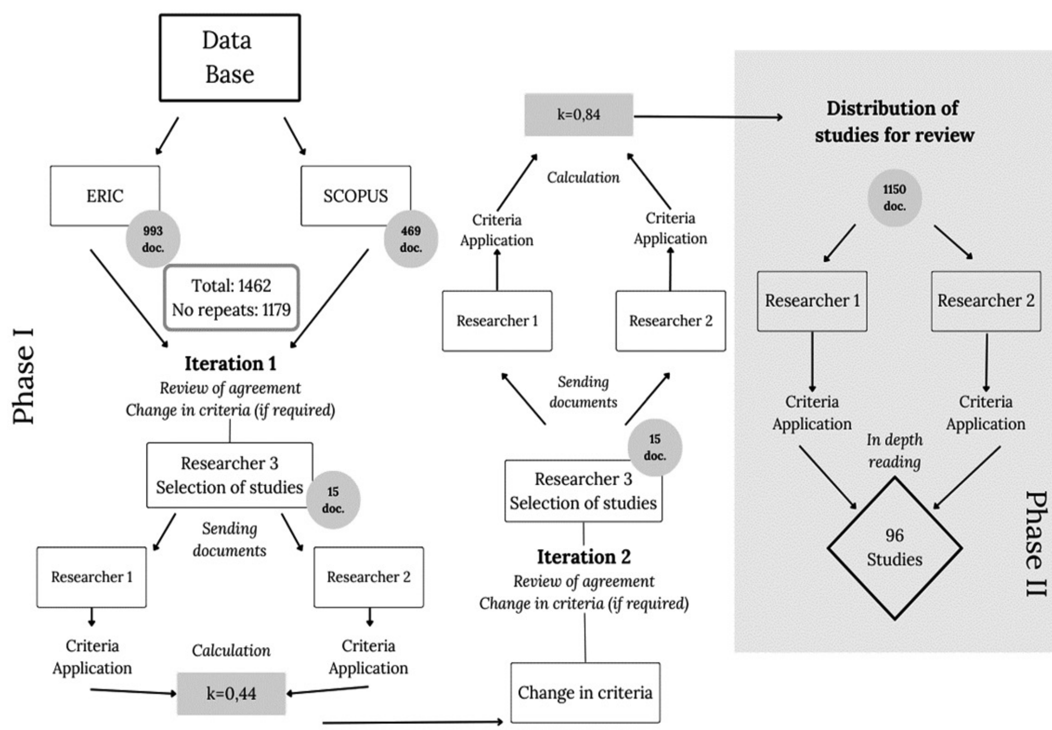
Inclusion criteria	Exclusion criteria
Peer-reviewed research articles and book chapters.	Proceedings of non-peer-reviewed academic events.
Articles and book chapters focusing on pre-service teacher education in mathematics and science.	Documents focused on the preparation of technology or engineering teachers, or teachers in other areas different from mathematics and science. Studies aimed at in-service mathematics or science teachers. Integration of STEM Education in elementary and middle school education.
Documents that focus on strategies, methodologies, curricular designs, and practices contributing to the initial preparation of mathematics or science teachers in STEM.	Papers focused on processes such as modeling or mathematical or scientific reasoning whose objective is not related to the initial preparation of mathematics or science teachers.
Documents explicitly related to teachers' perceptions, identity, meta-analysis or points of view if they derive from a STEM integration proposal (intervention or educational experience).	Papers related to perception, teacher identity, meta-analysis, gender studies, or teachers' views that do not contain STEM integration proposals or, if mentioned, are not described.

Thus, as shown in Table 1, the inclusion and exclusion criteria allowed for the selection of documents that considered elements of engineering and technology if they were used for preparing future mathematics and science teachers. Documents focused on other teacher preparation levels or other disciplines were excluding. Consequently, it was possible to establish the inclusion of research on educational experiences for initial teacher preparation as a premise for this review. Using the preceding criteria and the research questions, two search equations were defined, one for mathematics education and the other for science education, aimed to incorporate the most relevant characteristics of teacher education involving STEM approaches in these areas.

Additionally, Wohlin et al. (2012) emphasize the need to develop strategies to find primary studies, avoiding many documents that seem to be of interest but are not. In the case of this review, it is worth noting that not all research alludes to the STEM (or STEAM) approach in the same way. That is, it is possible to find references to this term from denominations such as: "STEM Education", "integrated STEM", "STEM approach", etc. In addition, there are multiple conceptions of initial teacher education. Consequently, we generated search strings using generic terms such as "mathematics teacher", "science teacher", "STEM" or "STEAM". The search strings we used in both databases were the following:

- ("mathematics preservice teacher" OR "mathematics pre-service teacher" OR "mathematics teacher") AND ("STEM" OR "STEAM")
- ("science preservice teacher" OR "science pre-service teacher" OR "science teacher") AND ("STEM" OR "STEAM")

Figure 1 Phases to document selection and review reliability



After carrying out an initial search, we found 1462 documents. Then, we unified the information and eliminated repetitions and obtained 1179 documents. Subsequently, we reviewed the title, abstract and keywords in correspondence with the review questions and the inclusion/exclusion criteria; as a result, we obtained 135 documents. Through in-depth reading and discussion of some documents among the two authors of this article, 96 documents were selected. We understand that STEM Education is a field in an embryonic state (Goos et al., 2023); therefore, new acronyms are often generated to emphasize understandings of STEM Education and relationships between different disciplines. Therefore, the results of this review are scoped according to the criteria and designations mentioned above. We proceeded to describe more elements regarding the selection of documents and the reliability of the review.

3.2.1 Document Selection and Review Reliability

To guarantee the quality of this review, we carried out a two-phase process of document selection and reliability of the review, following the phases proposed by Pérez et al. (2020). In the first phase, one researcher (external to this publication) randomly selected 15 studies from those obtained from the search strings. These documents were evaluated by two other researchers (the two authors of this article) based on the inclusion and exclusion criteria. We used the value of *Cohen's Kappa* statistic (K) and obtained a result of $K = 0.44$ in this first phase. Subsequently, we adjusted the inclusion and exclusion criteria again. After that, we repeated the process and obtained $K = 0.84$, which indicated an acceptable agreement on the selection of the documents. In the second phase, we distributed the remaining documents for analysis. This process is illustrated in Figure 1.

3.2.2 Document Analysis

Initially, we followed the selection process with 20 documents. From this first exercise, we met to discuss the results, established some data patterns, and assessed the pertinence of the coding system. In this meeting, we discussed our divergences until we reached some agreements. Based on the adjustments, we reviewed the full texts of all eligible articles and coded them using thematic analysis (Braun et al., 2019). The coding scheme allowed us to perform a general characterization of the papers in terms of countries, year of publication, and teachers' disciplinary field (science or mathematics), as well as the future teacher's preparation strategies. As a result, the two following themes about the initial education of mathematics and science teachers emerged: (1) roles of STEM Education and (2) methodologies for educating future teachers. Subsequently, we discussed the research trends and reports identified in the documents. We also identified diverse strategies to articulate STEM disciplines and different points of view regarding such interdisciplinarity.

3.3 Reporting the Review

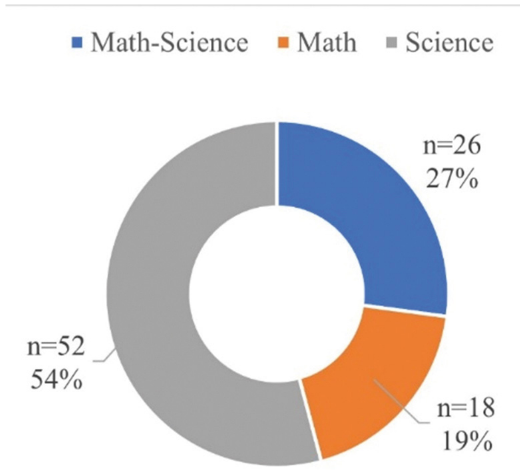
In reporting the review, it is necessary to consider the intended audience. This review seeks to inform teacher educators and researchers in Mathematics Education and Science Education about how the STEM approach has been integrated into initial teacher education in these fields. In that sense, this audience can find elements of how the review was conducted, the main issues reported in the literature, and the conclusions and implications for teacher preparation that can be derived from them. We hope this review generates guidelines for the initial education of mathematics and science teachers in theoretical, educational, and curricular aspects of STEM, including discussions regarding its naming.

4. Results and Discussion

In general terms, there is a growing interest in research on STEM in teacher education. It is appreciated in the notable growth of scientific articles during the period under review (a single paper in 2012, increasing each year, until reaching a maximum of twenty-one documents in 2021). The United States has been one of the countries with the highest rate of publications and one of the pioneers in the development of the STEM approach, being the origin of first year papers. After 2015, the contribution of the United States and Turkey stands out with 39 and 24 papers, respectively, corresponding to 66% of the reviewed papers. Globally, a significant contribution from European and North American countries is evidenced, while African and Asian countries have lower participation. It is noteworthy that, under the search criteria used, no document was found from the Latin American region.

We also found that the STEM approach studies have gained great interest for initial preparation of science teachers; among the proposals of the Next Generation Science Standards (NGSS), the integration of the STEM approach in science education is suggested, both from interdisciplinary processes as well as from articulation strategies such as engineering design, project-based learning, and computational thinking (Deniş, 2020; Marco-Bujosa, 2021). Furthermore, the concern with the initial preparation of mathematics teachers in STEM is more recent and is still under exploration. In total, we found 52 papers for pre-service science teachers, 18 papers for pre-service mathematics teachers, and 26 papers for joint initial preparation of science and mathematics teachers. These findings provide additional evidence to the results of Carmona-Mesa et al. (2019) who observed that mathematics teachers require further training in disciplinary content integration and collaboration with teachers from other disciplines. An additional aspect that may contribute to these results is that "it is still unclear what it might mean to learn mathematics in an integrated approach to multi- or inter-disciplinary contents, processes, or problems" (Goos et al., 2023, p. 1212). The distribution of topics is shown in Figure 2.

Figure 2 *Teacher subject distribution*



The study also showed that the greatest production of studies is concentrated in the preparation of secondary-school pre-service teachers, which corresponds to a total of 43, followed by 35 for primary-school pre-service teachers. We also found some studies (n=3) that integrate preschool, primary, and secondary pre-service teachers, other studies (n=2) corresponding only to preschool pre-service teachers, and one study concerning higher education teachers. However, it is important to point out that 24 documents out of the total do not state the aiming level of the participating pre-service teachers. In addition to the above characterization, the analysis of the 96 selected documents showed important subjects and trends in education strategies (for more details of the characterization, see appendix). The main results on these subjects are presented below.

4.1 STEM Education Roles

In the review, we aimed at identifying the roles that STEM Education has played in teacher education, both in research and in the design of education programs. This task is important because it provides information on trends in the adoption of the STEM approach, on its relationship with teacher education strategies and because it may contribute to delimiting future work tendencies.

We identified and grouped three main roles of STEM Education. The first role refers to STEM Education as a conceptual, theoretical, or methodological research tool used to study other research objects. In this group, STEM is employed to design instruments, support intervention proposals, understand perceptions or opinions, study skills, justify the presence of several disciplines, or as an instrument of analysis, among others uses. In other words, aspects associated with STEM Education are addressed but an actual definition or possible conceptualizations of STEM are not studied. A large part of the reviewed research was assigned to this group (n=70), where STEM Education implies linking elements of at least two disciplines, involving holistic, transdisciplinary, interdisciplinary, and multidisciplinary work, or covering terms such as STEM Education and integrated STEM Education. Some of these studies present different views regarding relationships between disciplines when integrating STEM into teacher education (e.g., Galadima et al., 2019).

The second group of studies refers to the nominal presence of the term STEM, that is, unlike the previous role, studies in this group do not have an explicit conceptualization or description of STEM Education or its implications. Thus, the term STEM is recurrent to refer to the disciplines of the acronym or to some type of relationship with them, such as the teachers who teach them, the curricula, or associated professional fields. The number of documents in this category is considerable (n=24), which draws attention to the popularity of the term in academic texts and the existence of an international tendency that recognizes and demands preparation in these disciplines.

Finally, two papers are reported under the "object" role. The studies in this group are concerned with conceptualizing or discussing theoretical elements of STEM in teacher education while establishing relationships with other theoretical or methodological objects. For example, one of these studies (Kertil & Gurel, 2016) presents a theoretical discussion on the contributions of mathematical modeling to the conceptualization of integrated STEM Education, reporting current perspectives on STEM Education, advances in mathematical modeling (in the field of mathematics education), possible relationships between them, and two experiences with teachers—one based on mathematical modeling and the other on project-based learning. In another study, Steele (2016) draws attention to the need to establish connections between STEM and ethics education, not only because of the interest that social-scientific issues bring to the students, but also because of the need to make moral reasoning and be reflective about the implications of bad-or-good decisions in STEM Education. The author presents three ethical frameworks that can be explored: Consequentialism, Virtues Ethics, and Sustainability Ethics.

These three roles of STEM Education in the research reviewed correspond to the wide range of possibilities, interests, contexts, approaches and perspectives that STEM Education has within educational research in general and within education in each discipline represented by the acronym. The identification of these roles makes it possible to understand, like Goos et al. (2023), that interdisciplinarity seems to be at the heart of the uses of the term STEM Education in research.

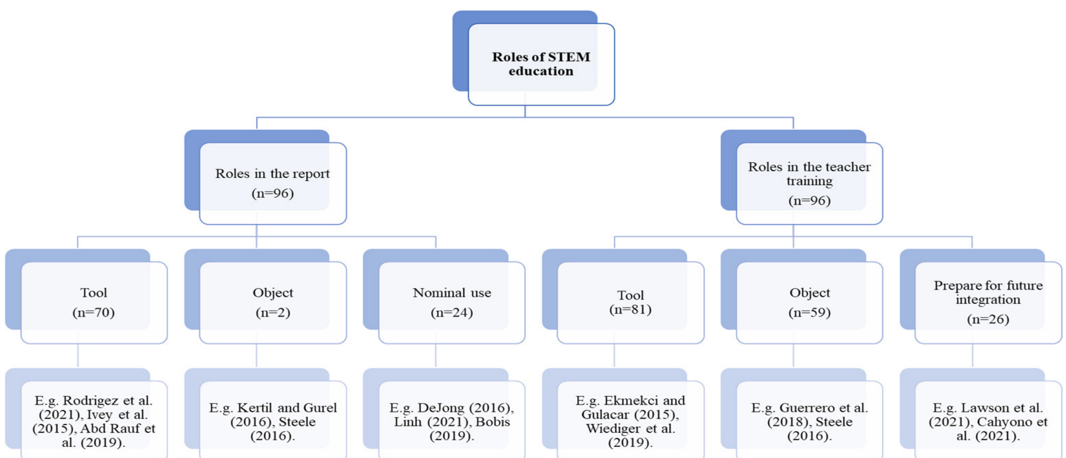
Regarding the roles that STEM Education has adopted in teacher preparation programs, it was possible to determine three tendencies (Fig. 3). The first one, called medium (n=81), corresponds to those works where STEM Education is presented as a tool or vehicle for the development of competencies or skills, the change of attitudes or perceptions, and the development of pedagogical, disciplinary, curricular knowledge, among others. STEM Education was also present as an object/content for teacher preparation (n=59). In this case, the reports present instances where teachers are taught content on STEM-related epistemologies, strategies for STEM teaching, ways of integration, on case studies about STEM conceptualization, and the description of STEM-based programs and courses. Finally, some documents proposed preparing teachers to promote integration exercises in their future practices (n=26). In this group, the percentage difference between mathematics or science teacher education is not significant; however, it is remarkable that out of 26 documents, 11 correspond to science (42.3%), 8 to mathematics (30.8%), and 7 to both mathematics and science (26.9%). These numbers show a tendency for integration exercises for future professional practices of mathematics teachers (involving 44.44% of the documents), compared to 21.15% of the documents for science teachers.

According to Huang et al. (2022), STEM teacher professional development programs are a way to foster the quality of STEM instruction.

Therefore, to inquire into how STEM Education discourses have been used in these programs can contribute to delimiting the contents, methodologies, purposes and scopes in training. In this aspect, the knowledge of STEM Education as a medium, content to be learned by teachers or methodological tool to enrich the teaching of a discipline, not only nurtures the disciplinary and interdisciplinary approaches of STEM Education, but also suggests delimiting and establishing more dialogues between different forms of knowledge, the needs of future teachers in their own contexts and the teacher educators and researchers.

Three dimensions considered for STEM roles were mutually exclusive, while the role regarding teacher preparation was not, as some papers addressed several educational purposes. In this sense, it is worth noting that, for the papers that use STEM in a nominal way (n=24), 91.67% (n=22) considered STEM as a teacher preparation tool, while only 29.17% (n=7) considered STEM as an object of education. Only 16.67% of the papers (n=4) considered STEM preparation for integration in future practices. These results contrast with the fact that when the report refers to STEM as a tool (n=70), 81.43% use STEM as a medium (n=57), and 71.43% (n=50) consider STEM as an object of preparation. That is, there is a considerable increase concerning nominal STEM use, while only 31.43% of the documents (n=22) deal with preparation for integration. This result shows that a nominal use of STEM rarely includes teacher preparation processes for integration or future STEM Education; however, a focus on skill development (sometimes in a monodisciplinary manner) and single STEM competencies is frequent.

Figure 3 Roles of STEM Education



Finally, we would like to draw attention to the use of the terms "interdisciplinary" and "interdisciplinarity", which have been strongly associated with STEM Education. We traced the explicit way in which these terms have been used in different documents and their relationship with STEM and teacher education. In this sense, it stands out that, geographically, Turkey is the country where these terms have the highest presence (23 of 24 papers). Of the total number of papers, the term "interdisciplinary" appears in 51, while "interdisciplinarity" appears in 2 (the use of the terms in references or journal names was not considered). Of these 51 documents, most use STEM as a tool (n= 46) and in a smaller proportion in a nominal way (n=3), or as an object (n=2). In the teacher preparation category, we found that, out of these 51 papers, an important part (n=16) addresses preparation on integration for future practices, while a larger number (n=38) considers STEM as an object of preparation and most of the papers (n=42) use STEM as an education tool. As expected, a large ratio of the papers that use STEM nominally in their research do not explicitly address interdisciplinarity. This contrasts with literature that considers STEM as an interdisciplinary approach (e.g., Siew et al., 2015; Cahyono et al., 2021).

One paper that uses the term interdisciplinarity considers it a challenge for STEM teaching and associates it with knowledge of other areas and the development of projects. In a second document, interdisciplinarity is implicitly contained in the acronym STEM; however, it is not clear in what sense it is implicit and what implications it has for teaching and research. Concerning the use of the term "interdisciplinary," we found varied uses and meanings. Among these meanings, we highlight the following: (i) interdisciplinary as an adjective that accompanies terms such as activities, experiences, skills, thinking, cooperation, STEM Education, approach, nature, work, learning, problems, links, etc; (ii) interdisciplinary as an instructional model to promote integrated curricula; (iii) interdisciplinary as one of the different levels of integration of STEM Education (others are mono, multi, and transdisciplinarity); (iv) interdisciplinary as part of the nature or characteristic of STEM; (v) interdisciplinary as a product of STEM; (vi) interdisciplinary as problem-solving with the use of several disciplines or the participation of people from different areas. Although "interdisciplinarity" appears in several documents, it is neither obvious nor automatic to understand the nuances assumed by the practices, skills, and concepts that are denominated in this way, especially when interdisciplinarity itself begins to constitute an object of study of growing interest in mathematics education (Williams et al., 2016). In this sense, broadening the discussions regarding the role of interdisciplinarity in STEM Education helps to delimit and understand the relationships among the disciplines that make up the acronym and to reduce possible inconsistencies in the use of terms such as mono, multi, inter, or transdisciplinary (Davis et al., 2019). Future revisions should focus on this aspect.

4.2 Methodologies for Educating Future Teachers

The studies analyzed in this review show that researchers in the fields of science and mathematics education have been interested in finding different preparation possibilities for STEM approaches. We identified education formats, number of hours, and links with other professionals or with teachers at different levels of education. Likewise, we coded the methodological strategies, either as an articulating axis for the disciplines of the acronym or as an integrating bridge from a more holistic perspective. At a global level, it is possible to affirm that the studies on how to structure teacher preparation processes focus on making a later integration in teachers' professional practice possible. Additionally, these methodological choices are a response to the educational purposes established in the interventions. Thus authors, such as Deniş (2020), for example, argue and highlight the value and use of engineering projects to generate an impact on the perceptions that science and mathematics teachers have about the competencies of the 21st century and on their teaching strategies.

Reflections on the importance of including elements of STEM Education in initial teacher preparation have led us to consider short-, medium-, and long-term intervention proposals, which we call lessons, courses, and programs, respectively. The most frequently used type is the course (n=49), followed by the lessons (n=17) and the programs (n=16). Nine papers employed strategies other than these, such as invitation to research processes, seminars, or communities of practice. Five papers were not possible to frame in any of the mentioned categories. Although a total of 68 documents do not refer to the number of instruction hours, it is possible to deduce that lessons range between 1 and 8 hours, courses comprise a much wider range, varying between 4 and 150 hours, while programs have a less precise report of their temporality due to their extension and scope.

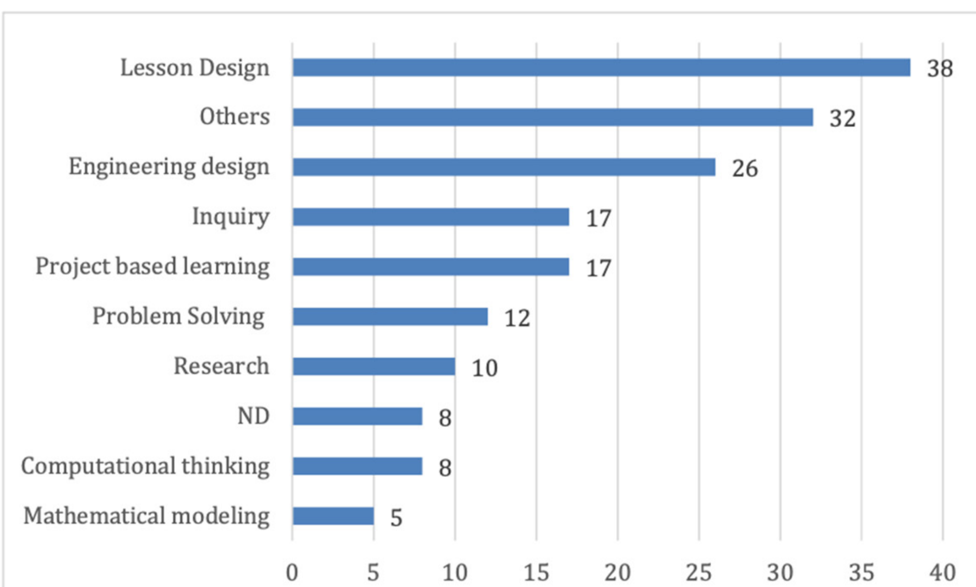
Regarding courses (n=49), we found different formats, such as the adaptation of existing courses in which discipline-specific methods stand out (Bartels et al., 2019; Harlow et al., 2018) by re-directing learning processes and adopting elements of the STEM approach. We also found new courses added to initial teacher education programs. One such course is presented by Kuc̨ük (2021). It addresses the interdisciplinary nature of STEM and the main elements of each discipline. It establishes coordinated approaches in which STEM activities are presented, analyzed, and evaluated. Finally, future teachers design their lessons based on the elements explored in the course. In another research project, an iSTEM (integrated STEM) course is presented focusing on different levels of integration: Single, Combined, Multiple, Engineering Projects, and Fully Integrated STEM disciplines (Galadima et al., 2019).

Lessons (n=17) correspond to brief encounters with a significant number of training proposals (n=15) using the STEM approach as a tool to develop specific skills. These lessons are usually part of a course that has a previously established intention. Thus, future science teachers study specific discipline concepts such as energy, circuits, and acid-base chemistry from a STEM perspective. Regarding future mathematics teachers, there is a clear tendency to encourage STEM practices through dialogue with teachers from other disciplines or through the design and evaluation of lessons.

Regarding education programs, we also found two trends. The first and the most frequent corresponds to complementary programs in the curricula, among which the Summer Programs stand out. These programs generate collaborative spaces with different engineering, technological, mathematical, or scientific institutions and create spaces for the convergence of professors from different disciplines and levels, allowing a joint and horizontal learning process (Bowen et al., 2018; McCollough et al., 2016). The second trend, although not equally frequent, is the curricular design of complete initial teacher education programs in university institutions (Jakopovic & Gomez-Johnson, 2021; Krell et al., 2015). This fact evidences the growing importance of STEM beyond its disciplinary integration role, emerging as a new discipline in its own right (Kennedy & Odell, 2014). One of the issues that made it difficult to characterize those programs was the lack of description about the methodological elements that constitute them, specifically the time ranges.

At a general level, collaborative work is one of the main strategies to promote the development of STEM competencies in teachers from different disciplines. It evidences meeting points and articulating axes, to solve problems, and to gain confidence with interdisciplinary challenges. The scenarios in which future teachers work jointly with other undergraduate students and with professionals from other disciplines are common. It is also common to observe formative spaces where teachers from different specific areas or different levels converge, working jointly with graduate students or in-service teachers. These scenarios prepare future teachers for dialogic processes with future colleagues from different disciplines and the generation of articulated proposals in their professional performance. This result extends the statement by Anita et al. (2021) that collaborative processes become an important input for STEM Education, not only for future mathematics teachers, also for future teachers of other STEM areas, such as science, in all educational levels. However, details are rarely given on how this teamwork can be organized (Thibaut et al., 2018), especially in teacher education.

Figure 4 *Strategies associated with STEM Education in teacher education*



Regarding the type of strategy to direct teachers' actions in STEM-related educational processes, we used the following coding: lesson design (n=38), engineering design (n=26), project-based learning (n=17), inquiry (n=17), problem-solving (or problem-based solving, n=12), research (n=10), computational thinking and related (n=8), mathematical modeling (n=5), others (n=22), and not declared (ND, n=8). Figure 4 illustrates the distribution of the different strategies. From this information, we point out two issues. Firstly, from each of the documents, it was possible to reference one or more strategies and, secondly, under the code of "computational thinking" we grouped strategies related to programming and robotics processes; although they are not equivalent, they are usually closely associated in the literature. Even if engineering was not strongly related to mathematics in the study by Anita et al. (2021), in this review we found that Engineering Design is a frequently employed process in pre-service preparation for both mathematics and science teachers.

According to the results, the most popular strategy is lesson design. This is a highly adopted strategy because it provides teachers with tools both in the pedagogical field (through evaluation exercises and critical discussion of designs) and in terms of knowledge about STEM and its integration in the classroom. Evidence of this statement is that 78.95% of the studies that use lesson design are related to one of the other strategies, for example, lesson design for inquiry development or engineering design (French & Burrows, 2018; Poonpaiboonpipat, 2021). In addition, from 2016 onwards, there is evidence of greater inclusion of engineering design strategies; however, for the case of future mathematics teachers, the exploration of engineering elements is much more recent, the first experience was reported in 2019 (Appendix). Following the design of lessons, we found a variety of strategies that were grouped within the code "others," including activities associated with case studies, experimentation, participation in lectures, and the formation of communities of practice, among others. It suggests that the adoption of STEM in education has revealed a diversity of possibilities and dialogic processes between different approaches and their pedagogical and disciplinary aspects.

Following Thibaut et al. (2018), these strategies, while different, can be presented in a unifying way. We hope that this review offers elements to discuss a five-dimension framework presented by the authors, namely, (i) integration of STEM content, (ii) problem-centered learning, (iii) inquiry-based learning, (iv) design-based learning, and (v) cooperative learning. We consider that while many of the strategies may be linked, it is still necessary to study different alternatives to establish these links and their implications for teaching and learning STEM disciplines. The strategies reported in this review can be framed with design principles for effective teacher professional development reported by Lo (2022). These design principles were constructed from research conducted with K-12 teachers. Despite this consistency, further studies are needed to inform ways to transfer these findings to future teacher education as the nature of the programs is often different. Our results also complement the Huang' (2022) review where learning by design, scaffolding authentic experiences, collaborating with peers, reflecting on practice, discourse between teachers, mentorship, were reported as approaches for professional development and teacher preparation.

This systematic review shows that, in the preparation of future mathematics teachers, strategies based on other disciplines are frequently considered. Although it can generate interdisciplinary opportunities, there is no evidence of a systematic effort to state and develop possible relationships between strategies, including traditional strategies in the field of mathematics education such as modeling and problem-solving. That is, even though some studies propose tasks associated with more than one strategy, such as computational thinking and mathematical modeling (Flores, 2014), these are presented as independent tasks. Consequently, there is still not enough empirical evidence, nor theoretical frameworks to illustrate the nature of these relationships, as well as the elements of each strategy that may be convergent, divergent, or complementary.

A possible interpretation of the non-explicit links between the different strategies is the lack of clarity regarding the implications of interdisciplinarity in teacher education (Castrillón-Yepes et al., 2023). Some studies report processes related to interdisciplinarity such as inquiry, mathematical modeling, problem-based solving, research, etc. Interdisciplinarity is also considered a need in teacher education, as a requirement of 21st-century skills and competencies, as a necessity to meet professional challenges, as a desirable condition of teachers' designs (interdisciplinary activities), and as an organizer of teachers' activity (interdisciplinary work, interdisciplinary cooperation or collaboration). This multiplicity invites us to consider not only the relationships that can be established between different teacher education strategies, but also the need to incorporate theoretical and methodological elements of interdisciplinarity in teacher education; in other words, interdisciplinarity become as a content of teaching.

The above results show a growing interest in STEM Education. In addition, roles of STEM Education and strategies that contribute to articulation have been recognized, such as engineering design, project-based learning and computational thinking. However, it is still necessary to promote and systematize interdisciplinary processes and to define what teaching or learning in an interdisciplinary logic implies within the framework of STEM Education. It is not yet clear which are the contents that can be the object of training for future teachers, nor the vision on interdisciplinarity that underlies the training bets of these professionals. Therefore, understanding how interdisciplinarity and STEM Education are present in the professional training of future teachers remains an open task in research. The review also shows that the term "STEM Education" does not automatically imply integrated approaches, and that this term takes on different nuances in research and teacher education. Moving forward, there is a need not only for conceptual and methodological frameworks on STEM Education, but also for long-term studies that show how teachers (or future teachers) incorporate it into their professional practices and the challenges this entails in different contexts.

5. Conclusions and Final Remarks

This review shows that the notion of *STEM Education* and their relatives have gained considerable momentum in research, development and practices both science and mathematics education during the last decade. This reflects a growing need to investigate contents, competencies, procedures, among others, in these fields and their interdependences.

The review shows a terminological and role diversity when researchers and pre-service teacher educators analyze, characterize, and design activities and programs for training mathematics and science teachers. We presented the main roles and methodological choices incorporated in the research on the initial training of mathematics and science teachers. These two major themes show trends such as the integration of STEM as a tool in reports and as a means in teacher preparation. The scarce presence of STEM Education considered as an object suggests the need to generate proposals where teacher preparation experiences are developed to broaden the view of STEM based on theoretical discussions supported by empirical evidence.

Although the importance of generating relationships and considering multidisciplinary, interdisciplinary and transdisciplinary knowledge has been mentioned, the role of interdisciplinarity and other levels of integration is often blurred in the reviewed frameworks. Clarifying these elements could contribute to a better understanding of the possible relationships between disciplines, identifying the components to be articulated, and finding ways to achieve this.

The reviewed documents provide empirical evidence on the opportunities offered by including STEM Education approaches in early teacher preparation, in terms of the impact on their future practices, their conceptual knowledge about STEM, their perceptions, and their self-efficacy. This has been achieved based on different visions, conceptualizations and ways of integrating STEM, indicating the necessity to promote spaces for epistemological and critical discussion of the inclusion of STEM both in teacher training and in schools. Additionally, we still need research on the system of purposes, strategies, methodologies and curricular designs vis-à-vis each individual discipline education, and on the interdependencies with education in other disciplines.

It is increasingly common to adopt an integrated approach to STEM, engaging in collaborative exercises with teachers and professionals from various fields. These practices not only show future teachers' knowledge that can be articulated, but also prepare them to collaborate and work with others. Nevertheless, it is necessary to consider adjustments in teacher training according to curricular and contextual conditions.

Finally, this review offers evidence of methodologies and strategies used in the initial training of mathematics and science teachers, and also allows us to recognize the diversity of understandings and uses of the term, underscoring the importance of generating proposals based on theoretical discussions and supported by empirical evidence, to clarify the vision of STEM in research and in teacher training proposals. Likewise, identifying roles and strategies offers evidence to discuss contents, strategies, purposes and arguments for the design of teacher education proposals.

Acknowledgments

This work was supported by the Committee for Research Development (CODI) of the University of Antioquia for the funding of the project "Fundamentación y desarrollo de una propuesta de formación STEM para futuros profesores de matemáticas", code: 2018-22989. Although they are not responsible for the content, we would like to thank Daniel Andrés Quiroz-Vallejo and Jaime Andrés Carmona-Mesa for their comments and support in the development of this literature review.

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Appendix

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