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A systematic review of STEM teaching-learning methods and activities in early childhood

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Abstract
This study aims to help educators and researchers to understand the pedagogical practice of STEM in early childhood and its impact. To support this, 29 publications related to STEM teaching-learning methods and activities were selected in the period between 2014 and 2023. The study covers the distribution of research over time by countries, the analysis of keywords, research goals and results, research methods, STEM domains, as well as emerging teaching-learning methods and activities, and the presentation of research limitations. According to the results, digital activities and impact studies have become dominant in early childhood STEM activities. There is a small number of studies presenting educational practices related to the relationship between sustainability and STEM. It was also revealed that impact assessments regarding early childhood STEM education need further development and improvement.

Keywords: early childhood, STEM education, teaching methods, student activities, impact assessment

INTRODUCTION

STEM is a meta-discipline encompassing science, technology, engineering and mathematics (Lantz, 2009). In terms of teaching and learning, it is a topological hyperspace in which children solve problems at the crossroads of the STEM meta-discipline and the various dimensions that influence learning, while developing cognitive, affective, and effective personality traits. The acronym STEM, first known as SMET by the National Science Foundation (NSF), began to be used in the USA in the 1990s and early 2000s (Hallinen & Rogers, 2015).

STEM education and related research is now present in all continents. According to Yang et al. (2023), the number of STEM-related publications changed in three main phases over the period between 2004 and 2022. Compared to the first period (2004-2010), when STEM-related research began, 26 times more publications were published in the second phase (2011–2018) and one hundred and twenty times more publications in the third phase (2019-2022). The authors of the studies, published since 2004, struggled to understand and study the interdisciplinary nature of STEM in the early period, therefore thy focused on individual disciplines. In the second phase, researchers reported studies of student achievement, motivation and gender differences in STEM education. The third phase is when a large number of studies on teachers' perceptions, professional qualifications and training, and the practical implementation of STEM were published. Recent studies analyze the relationship between STEM and sustainability.

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Contribution to the literature

- Contribution to educational practice and research of early childhood STEM education.
- Presentation STEM teaching and learning methods and activities. Providing lessons for the impact assessment of early childhood STEM education.
- Anticipate further opportunities for research development by demonstrating the limitations of research.

In chronological order, the number of STEM publications indicates an increase in the share of research on early childhood STEM education from the second period (Chai, 2019; Freeman et al., 2014; Wang & Degol, 2013; Yang et al., 2023).

The goal of STEM education is to develop an age-appropriate complex approach from early childhood, in possession of which the problems of nature and society would be approached and solved globally, appeared as the goal of integrated science education even before the emergence of STEM education. This is reflected in the first studies of integrated science education, which initially focused on its concept and goals (Frey, 1989). Even then, these publications, similar to the goals of STEM education, emphasized that through an interdisciplinary approach and learning, students acquire the skills to explain and solve complex problems of everyday life. Subsequently, the most outstanding research occurred from 1996, some of which studied the implementation of integrated science education and its problems (Green & Osah-Ogulu, 2003; Nampota, 2008; Sun et al., 2014). Although these studies were not focusing specifically on the implementation of STEM in early childhood, they were important because they provided ideas for pedagogical practice in STEM education.

Studies on the application of STEM in early childhood initially present the abilities and childhood characteristics that enable children aged three to eight to learn STEM. For example, Sharapan (2012) emphasizes that children in kindergarten are amazed by the phenomena of the world around them, try to explain them, while exploring, experimenting, observing, working with different materials and tools, i.e., they are able to engage with STEM activities. During these activities, although often not yet consciously in their knowledge and thinking (since young children do not yet have disciplinary knowledge in the scientific sense), connections between STEM disciplines begin to emerge, which lay the foundation for later complex thinking and the STEM approach (Moomav & Davis, 2010).

In the first half of the 2010s, early childhood STEM education research focused on the relationship between STEM and early childhood creativity (Corlu et al., 2014; Kim et al., 2014; Uret & Ceylan, 2021). STEM education's impact assessments on creativity have already clearly described, even if not always in early childhood, teaching and learning methods that have a positive impact on creativity. Such methods include teacher feedback to children in the learning process (Shen et al., 2021), design-based learning using engineering activities (Keana & Keana, 2016), applying arts and crafts activities as a complement to STEM education (Root-Bernstein, 2015), or systematic problem-solving (Stone-MacDonald et al., 2015; Yang et al., 2023). From the second half of the 2010s to nowadays, research on early childhood has complemented previous research by studying the effects of STEM education on communication, collaboration, socialization, problem-solving, critical thinking, engineering and computational skills, science process skills, mathematics abilities, and language literacy, as well as the conditions for implementing STEM activities (Nikolopoulou, 2022), the students' motivation for and interest in, STEM attitudes of students and teachers, the preparedness and perception of teachers related to STEM (Bjerknes et al. 2023; Yang et al., 2023).

Recent studies, however, are increasingly focusing on the issues of education to sustainability in early childhood STEM education (Rodrigues-Silva & Alsina, 2023). Ng et al. (2022) summarized studies on the analysis of STEM/STEAM teaching-learning methods in their integrative review and analyzed how levels and degrees of the integration of different disciplines occur in them (Vasquez et al., 2020). This is important because the transdisciplinary level is what best serves the goals of STEM in the personality development of children, laying the foundation for skills, complex knowledge and a global perspective that will later enable them to work effectively, creatively, and succeed in life.

Objectives of Sstudy

There is, however, a lot of uncertainty in early childhood STEM education, especially when it comes to effective teaching-learning methods and activities. However, the success of STEM education depends heavily on the pedagogical practice used for achieving STEM goals and requirements. To do this, STEM educators have to be professionally, pedagogically and psychologically well-prepared. They need to see which good practices, teaching-learning methods and student activities they can apply reliably and safely for the expected effect. This is why studies that describe and analyze the impact of a particular teaching-learning method and activity are very important to help STEM educators implement STEM in particular classroom or outdoor activities (Evangelou et al., 2010; Kazakoff et al., 2016; Sullivan et al., 2013).

These studies are also important for researchers because they can see examples of analyzing the pedagogical practice of STEM, moreover, they can develop and perfect them, and thus provide an increasingly accurate picture of the successful applicability of the applied teaching-learning methods.

Therefore, the aim of our study was to collect studies showing the impact of STEM teaching-learning methods and activities on children from the period between 2014 and 2023. By analyzing these publications, we aimed to help the pedagogical practice of STEM and its research using scientific-level, correct and reliable methods.

The questions of the research are the following:

1. What is the distribution of publications focusing on early childhood STEM teaching and learning methods and particular activities across geographic space and time over the time frame studied?
2. To what extent do keywords refer to teaching-learning methods and activities presented in the publications?
3. What is the frequency of the presented teaching-learning methods for the whole of the publications studied and for the studied period?
4. Which STEM domains are in the focus of the publications studied?
5. What research methods and tools were applied by the authors?
6. What particular examples of student activities and best practices occur?
7. What was the research purpose of the studied teaching-learning methods and activities and what were their results?
8. What are the limitations of the published research, and consequently what are the further research directions regarding pedagogical practice in early childhood STEM education and related impact assessments?

METHODOLOGY

PRISMA (preferred reporting items for systematic reviews and meta-analyses) guidelines were followed when composing the systematic review (**Figure 1**).

Eligibility Criteria

1. Original, empiric, published in peer-review, high standard open access journals (Scopus).
2. Describe early childhood STEM teaching-learning methods and activities involved in the study.
3. Analyze the effects of early childhood STEM teaching and learning methods and activities.
4. Related to the period between 2014 and 2023.
5. Published in English.

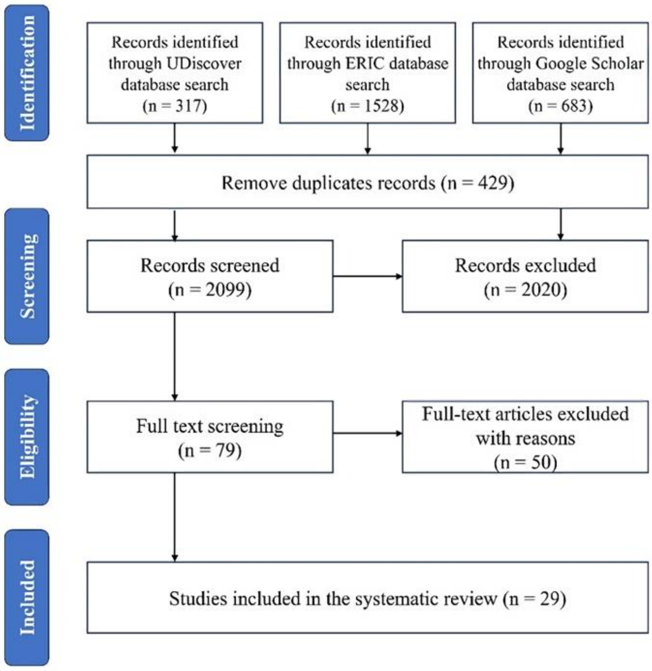

Figure 1. PRISMA flow diagram (Liberati et al., 2009)

Only reliable journal articles with the necessary data were studied, books and book chapters were not included in the sample.

Search Strategy

The search strategy established with the help of an expert from the local university library and eight researchers. The search was conducted in April 2023 using the UDiscover search engine and ERIC and Google scholar databases. The keywords and phrases "STEM in early childhood" OR "STEM education in early childhood" OR "STEM education in pre-school" OR "experience about STEM in early childhood" OR "teaching STEM in early childhood" were used to select publications.

The search strategy was the following:

1. The expert of the library found 2,528 records, 429 of which were duplicates.
2. Subsequently, in the screening phase, from the remaining 2,099 records, the researchers worked in pairs to select publications suitable for the research goal (four pairs of researchers who also consulted with each other). First excluded books and book chapters were excluded, then journals without empirical research, non-open access, non-peer review and non-Scopus journals were also excluded.
3. In the next step of the search, the titles, abstracts, and keywords of the publications were examined. By the end of this phase of the search, 2,020 records were removed. The four researcher pairs performed the search in this phase as well.

4. Full-text search and study of the remaining 79 records was performed afterwards based on specific criteria (year of publication, country in which the research took place, method and tools of the research, age studied in the publications, STEM domains covered by the published research and teaching-learning methods and activities, STEM teaching-learning method, STEM teaching-learning activity, research conclusion, research limitations and recommendations for future research). After that, 50 records were removed that only touched on teaching-learning methods and activities, or the impact and problems of teaching these methods, and the attitudes towards STEM were interpreted only regarding educators. Full-text search and analysis were also performed by the four pairs. After consultation of the couples, 29 publications were selected which met the objectives and questions of this systematic review.

The selected publications were analyzed related to the proportion of research on STEM teaching and learning methods in early childhood has changed over the selected time period (2014-2023). In doing so firstly the years were looked for when the studies were published and then conducted a frequency analysis by year. The geographical distribution of this research was also interesting. The countries and continents, where the research carried out were highlighted, and then the frequency of publications by country and continent was analyzed for the total number of publications.

In selecting the publications, it was important to ensure that the keywords reflected STEM teaching-learning methods and activities. Thus, the keywords provided in each publication were selected. Based on their frequency of occurrence for the 29 publications, a word cloud was constructed, making the most common themes of the publications studied more transparent.

The main aim of the study was also to analyze, which publications described teaching-learning methods related to early childhood STEM education in detail for the publications as a whole, and to analyze how many publications described given methods in the period 2014-2023 distributed by years.

In relation to the number of STEM teaching-learning methods and activities in a given publication that touch on all four STEM domains (science, technology, engineering, mathematics), and the number that touch on fewer than four STEM domains, the 29 publications selected were analyzed.

Particular attention has been paid to investigate the impact of the teaching and learning methods and activities. The reason for this was that it is more difficult to carry out a correct, reliable impact assessment in early childhood as there are few research tools and methods available. This is particularly true for quantitative

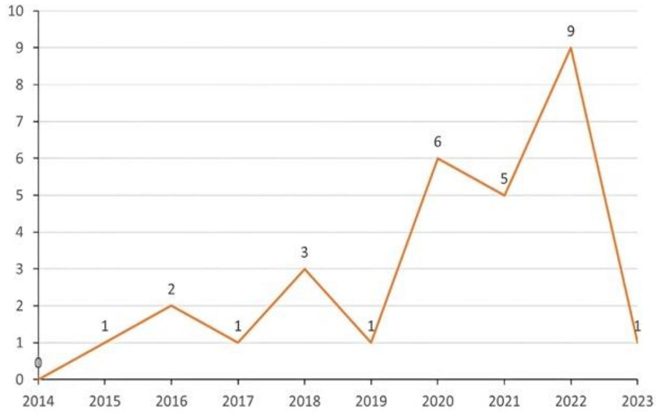

Figure 2. Distribution of studied publications in time period between 2014 & 2023 (Source: Authors' own elaboration)

methods. Thus, a search was conducted to view what the basic research method was in each publication (qualitative only, quantitative only or mixed), including the proportion of other pedagogical methods and tools that were observed.

Due to the diversity of STEM teaching-learning activities, they have been tabulated by publication in the context of the purpose of the research, the research method and tools, the STEM domains covered by the STEM teaching method and the main findings of the research. This qualitative analysis thus presents the given STEM activity in a research context rather than as an end in itself, allowing it to be viewed in the context of the different aspects of the research process.

Finally, the limits of the research were analyzed. The purpose of this analysis was to identify gaps and limitations that could be addressed to advance early childhood STEM education and research. In this regard, the limits of each selected publication was investigated, followed by the frequency of each type of limit for the publications as a whole.

Data Analysis

During the evaluation of the data, descriptive statistics was used to examine the frequency of the publication year, the country of research, keywords, teaching-learning methods, as well as research methods as a whole. The purpose of the research, STEM teaching-learning activities, findings, and research limitations were evaluated qualitatively.

RESULTS

Distribution of Studied Publications by Year & Country

The first research question was related to the temporal and geographical distribution of the selected publications in the studied time interval (**Figure 2** and **Figure 3**).

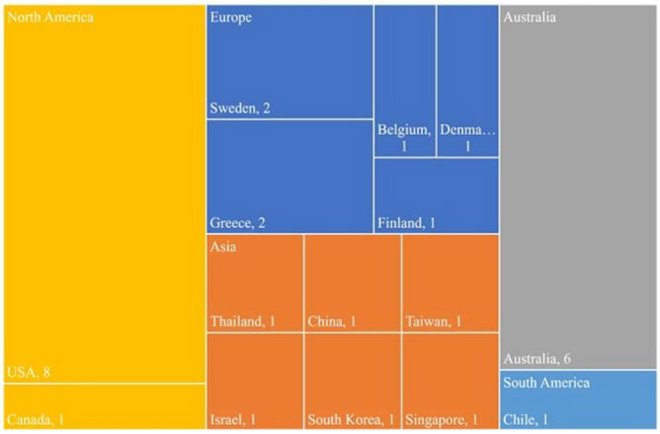

Figure 3. Distribution of studied publications by country of research (Source: Authors' own elaboration)

The studied publications (n=29) show an uneven distribution in the time interval 2014-2023. In 2014, no publications were found that matched the research objective of this systematic review. Most studies were published in 2022 (n=9), followed by 2020 (n=6) and then 2021 (n=5). In 2023, only one relevant article was found since the full year was not reviewed.

Regarding the distribution by country, most publications came from the North American continent (n=9). Within this, eight relevant studies were selected from the USA and one from Canada. Europe (n=7) was followed by Asia and Australia in equal proportions (n=6). While one research was selected for analysis from the South American continent (Chile). Considering the country of the topic of the studied publications the USA (n=9) and Australia (n=6) published the most publications.

Keywords in Publications Studied

The second question of this study regarding the keywords of the selected 29 publications was the extent those refer to the teaching-learning methods and activities presented in the publications. A word cloud was created based on the occurrence of each keyword (**Figure 4**).

The most frequently occurring keywords were early childhood (n=19), education (n=14) and STEM (n=13), followed by preschool (n=11), robotics and programming with equal frequency (n=8). The next most common keyword was engineering with seven mentions. Other examples include science education (n=6), play-based learning and elementary students with equal frequency (n=5), as well as inquiry teaching, mathematics education, scientific inquiry, problem solving, computational thinking. The frequency of the latter five keywords and terms is the same (n=4). The other keywords seen in the word cloud appear less than three times in the publications. However, they are highly diverse (n=67) and relate to skills to be developed, studying gender, motivation for STEM, and methods of

Figure 4. Word cloud composed based on occurrence frequency of keywords (Source: Authors' own elaboration)

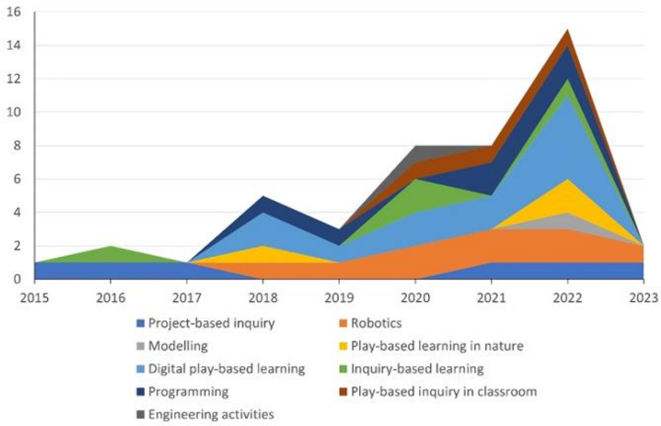

Figure 5. Distribution of teaching-learning methods occurring in studied publications by year (number) (Source: Authors' own elaboration)

research and teaching. Keywords referring to student STEM activities detailed in the publications were found in none of the publications.

Distribution of Teaching-Learning Methods by Years & Related to All of Publications

Regarding the third research question, the frequency of the teaching-learning methods discussed in the publications studied related to all the publications studied and to the time period studied (**Figure 5** and **Figure 6**).

Regarding the years studied (**Figure 5**), we analyzed which methods occurred in the greatest number of years since 2014. These included project-based inquiry and robotics methods (in six-six years studied), digital play-based learning (in five years) and programming (in four years). Similarly to the frequency in all publications, play-based inquiry in classroom (in three years), play-

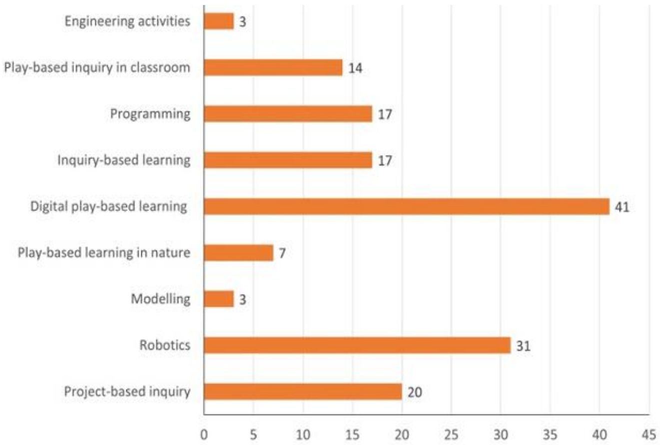

Figure 6. Frequency of teaching-learning methods occurring in studied publications (%) related to all publications (Source: Authors' own elaboration)

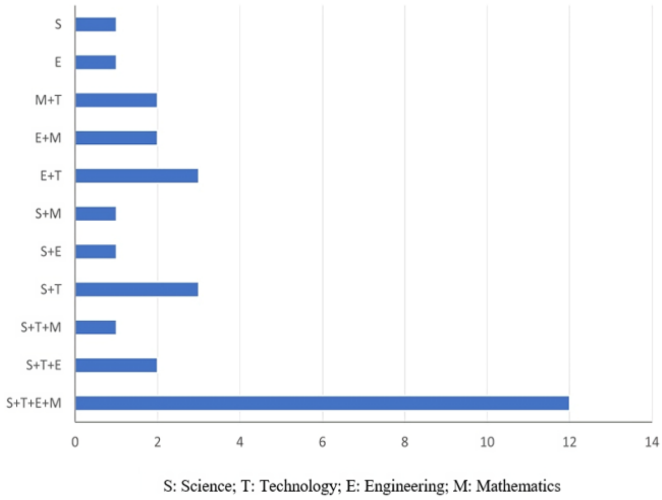

Figure 7. STEM domains in publications studied (n=29) (Source: Authors' own elaboration)

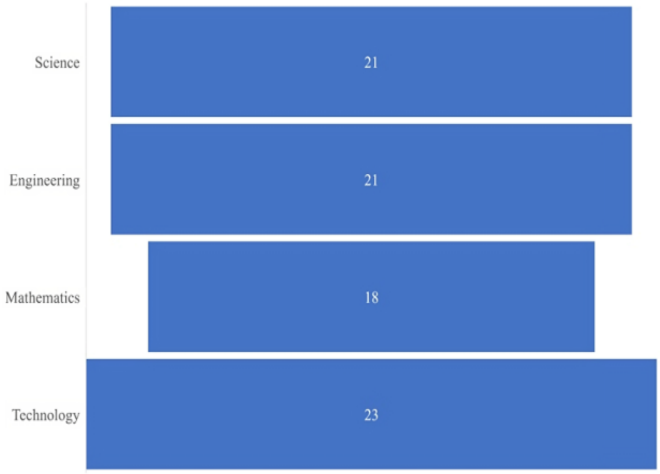

Figure 8. Occurrence (number) of STEM domains in publications studied (Source: Authors' own elaboration)

based learning in nature (in two years), modelling and methods focusing on engineering activities (one-one year) occur in the smallest number of years.

Regarding the years, it is clear that the frequency of digital play-based learning, robotics and programming methods increased the most between 2017 and 2022. The earliest methods used in the publications studied (2015) were project-based inquiry and inquiry-based learning, which can also be found in later years. From 2018 the descriptions of digital methods occur increasingly. Although playing is a basic activity in early childhood, the emphasis on play-based learning in classroom was only seen from 2019, while play-based learning in nature was described in the selected publications only in 2018 and 2020. The temporal distribution of individual teaching-learning methods also shows the rise of digital methods in the last ten years.

Regarding the distribution of individual teaching-learning methods in all of the publications (**Figure 6**), digital play-based learning (41%) and robotics (31%) methods were observed with the highest frequency between 2014 and 2023. This is followed by project-based inquiry (20%), programming and inquiry-based learning (both 17%), and play-based inquiry in classroom (14%). Play-based learning in nature is the lowest in 7% of the publications, modelling is in 3%, and engineering activities-focused methods are also found in 3% of the publications. Digital methods have therefore the highest frequency.

STEM Domains

As a fourth question, we wanted to know which STEM domains the selected publications focus on. We looked at how many of the 29 publications selected concern all four STEM domains (science, technology, engineering, mathematics) and how many concern not all domains (**Figure 7**).

Based on the analysis, the number of publications discussing four and two domains was 12 each, those involving three domains were three, and those focusing on one domain were two. The publications thus involved all four domains in the highest proportion, according to the concept of STEM. It is also remarkable and thought-provoking that the number of studies involving two domains is as high as that of those involving four domains.

The occurrence of each domain in relation to the 29 publications is presented in **Figure 8**.

No large differences were found between the occurrences of the domains. Technology domain is followed by science, then engineering and mathematics. When the four domains occur together, all domains are represented in equal proportions. Since the number of cases when all four domains occur together is 12, the number of the individual domains is the same (n=12).

Thus, the minor differences shown in **Figure 8** are due to the triple, double and single occurrences. Mostly due to the double occurrences, as their frequency exceeded that of the triple and single occurrences. Based

Table 1. Occurrence of further methods within basic methods in publications studied (n=29)

	Case study	Ethnographic design	Action research	Experimental	Quasi-experimental	Curriculum intervention
Occurrence (n)	10	6	4	2	3	2

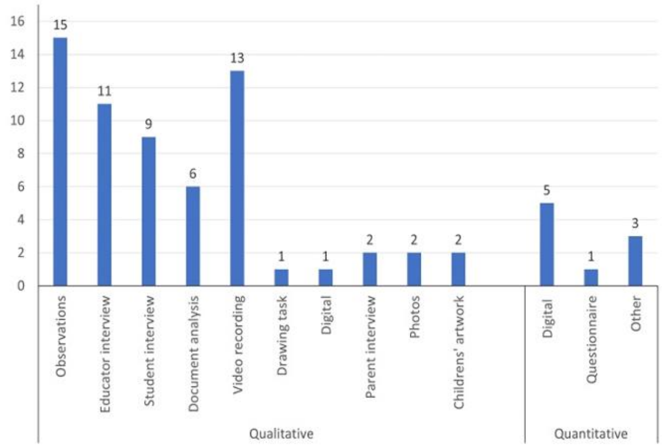

Figure 9. Occurrence of research tools (number) in publications studied (Source: Authors' own elaboration)

on **Figure 8**, technology, science or engineering occurred most frequently in the double and triple domain variations as well, while mathematics occurred least frequently.

Research Methods & Tools

The fifth research question focused on the research methods and tools used by the authors. To answer this question, we were looking for the basic research method (only qualitative, only quantitative or mixed) in each publication, and other characteristic pedagogical methods and tools within the basic research method. Among the basic methods, studies using only qualitative (n=17) methods had the highest frequency in all publications. The number of solely quantitative research was 3, and that of mixed studies was 9.

Further methods were used within the basic research methods (**Table 1**).

Case study (n=10), ethnographic design (n=6) had greatest occurrence, which can be considered qualitative methods and adaptive methods of studying young children. The occurrence of the additional methods shown in **Table 1** is smaller apiece. Each of these investigated the impact of certain teaching-learning methods or activities.

The tools used in the research of the publications show a diverse picture (**Figure 9**).

The proportion of qualitative research tools was greater than that of quantitative tools. The largest number of occurrences was found for observations (classroom and outdoor) (n=15), which is a traditional method in early childhood research, followed by video recording and its analysis (n=13), educator (n=11) and student interviews (n=9), and analysis of various documents and records (researcher diary, teacher notes, teaching and activity plans of teachers) (n=6). The rest of the research tools shown in **Figure 9** were used in one or two publications. Of the eight quantitative tools described, five are digital measuring tools (digital puzzle, robotics task, KIBO Project Rubric, Solve-Its), and only two types, questionnaire and other tools (e.g., Early Mathematics Ability-3: TEMA-3) are traditional research tools.

Research Objectives, Findings, & Teaching-Learning Activities

The sixth and seventh questions were associated with the specific teaching-learning activities appearing in the research, the objectives and findings of the research, the details of which were collected by publication are summarized in **Table A1**, **Table A2**, **Table A3**, and **Table A4** in **Appendix A**, which show all the characteristics of each study that are necessary to support and understand the objectives and findings of the research presented in the publications.

Limits of Research

In answering the eighth question, the limits of the studies and their recommendations for the future were analyzed. In 26 of the 29 publications, the authors detailed the limits of their research (**Table A5** in **Appendix A**).

Most research (n=13) considered that research methods needed further improvement. A higher proportion of researchers (n=10) also reported problems related to the organization of early childhood STEM education. The small number or lack of international research regarding the given research topic occurred in several cases (n=5). In two cases, it was admitted that the number of students studied was small and the sample was not representative, and two researchers also indicated that they did not receive sufficient financial support for the research.

DISCUSSION

Frequency of Publications by Year & Country

The distribution of the studied publications by year is consistent with the data reported by Chai (2019) and and Yang et al. (2023), according to which the number of studies on STEM education, including early childhood STEM education, increased rapidly between 2019 and 2022. This study also shows that the number of publications on teaching-learning methods and activities and their impact assessment increased from 2014 onwards and increased sharply in the period 2019-2022. During this period, a higher proportion of publications focused on early childhood STEM education using ICT tools and methods. Several studies have covered the potential applications of robotics and programming in preschool (Bezuidenhout, 2021; Fridberg & Redfors, 2021; Govind & Bers 2021; Kanaki & Kalogiannakis, 2022; Kewalramani et al., 2020; Liu et al., 2022; Murcia et al., 2020; Mitchell et al., 2022; Nam et al., 2019). As we are witnessing the development of this digital technology in education today, we can expect more studies on similar topics related to this age of students in the near future. Just like research into the relationship between STEM and education for sustainability is gaining attention (Campbell & Speldewinde, 2022; Liu et al., 2022).

The starting point of STEM education was the United States, where there was a need for teaching and learning science with a complex approach in the second half of the 1990s. The foundations, goals and requirements of this science education were formulated in the next generation science standards (NGSS Lead States, 2013) framework for science and engineering practices, disciplinary core ideas and crosscutting concepts, which implies the intertwining of science and engineering STEM fields. Requirements have also been formulated for the education of preschoolers. Thus, this document can be considered one of the first regulations to include elements of STEM education in early childhood in science and engineering. According to Chomphuphra et al. (2019), the United States and Australia are the two countries with the highest number of STEM-related publications until 2017. Similar data were obtained in our study. Most of the publications studying early childhood STEM teaching and learning methods and activities and their impact assessments relate to research conducted in the United States and Australia. Overall, the number of relevant publications in European and Asian countries was similar to the two leading countries, demonstrating the gradual spread of STEM education in early childhood in Europe and Asia over the studied period of 2014-2023.

Keywords in Publications Studied

For the second research question, we analyzed whether the keywords refer to the teaching-learning methods and activities presented in the publications. The most frequently used keywords (early childhood, education, STEM, preschool) include robotics and programming, which clearly indicates that a higher proportion of the publications studied deal with the use of digital technology in STEM education.

The keywords in the investigated publication also refer to STEM domains. Most of the keywords refer to engineering activities, but the terms science and mathematics education are also frequent. The technology domain occurs less frequently alone, it can be found indirectly in keywords related to digital technology (robotics, programming, ICT, digital technology, etc.). Among teaching-learning methods and activities play-based learning, inquiry teaching, problem solving, and project-based learning occur. Keywords related to skills to be developed, such as computational thinking or creativity, were also rare. Gender and girls were among the terms used to refer to research studying gender differences, suggesting that girls' participation and attitudes towards STEM are more closely studied in the early childhood STEM education process. Considering our second research question, the keywords primarily refer to the importance of STEM education in early childhood, the similarly weighted role of STEM domains and, to a lesser extent, the teaching-learning methods discussed in publications. Among these, digital technology as a method and age-appropriate playful learning dominate. No specific terms referring to STEM activity were found. In relation to STEM teaching-learning methods and specific activities, studies have emphasized the role of methods.

Distribution of Teaching-Learning Methods

This research question examined the distribution of teaching-learning methods discussed in the publications by year and across all publications. A similar analysis is presented in the systematic review by Larkin and Lowrie (2023) in which studies showing the role of STEM integration in the learning process in preschool and primary school in the period of 2016-2022 were analyzed. The methods found were categorized and the categories problem-based, inquiry-based, project-based, play-based, teacher directed, and non-specified were created. In their study, they note that the play-based method is of greatest importance in the age studied, and these appeared dominantly in the publications analysed by them.

In the publications studied by us, project-, inquiry-, and play-based learning were also emphasized, which we further broke down to refine them. Thus, considering the occurrences in publications, we encountered the application of digital-play-based, play-based learning in nature, play-based inquiry in classroom methods.

Today, the presence of digital methods is emphasized among early childhood STEM teaching-learning methods, which is why they (programming, robotics) should be considered separate teaching and learning methods or strategies. As well as modelling, which has outgrown its function of supporting understanding only in illustration and as in one of the publications included in our study (Speldewinde, 2022), it appears as an independent didactic task focusing specifically on this method. At the same time, modelling is also part of engineering activities. The latter can be considered an independent method if it is present in the STEM learning process for its own sake and specifically focused on engineering (Pattison et al., 2022).

This study confirmed the rise of digital technology in terms of the distribution of teaching-learning methods by year from 2014 to 2023. Publications were increasingly focused on the role of robotics, programming, and digital-play-based learning in early childhood STEM education in more and more years and also within a given year. The development of digital technology will bring more and more tools and methods to STEM education, therefore the number of publications in this field is expected to rise in the near future.

If we look at the different types of play-based learning as a whole, similarly to Larkin and Lowrie (2023), the publications analyzed here, regarding the distribution by years, mention this basic method the most, which justifies the role of play as the most important core activity in early childhood. Inquiry-based learning and project-based inquiry methods are present in research in all years studied, but not specifically because their direct impact would be studied. In addition to play, these have also become dominant basic methods in early childhood STEM education.

Analyzing the frequency of teaching-learning methods for all publications studied, we found consistency with the distribution by year. 62% of the studies involved certain types of play-based learning of which digital-play based learning was the most prevalent. In half of the studies, programming and robotics methods were encountered, and in one-third project-based and inquiry-based learning occurred.

STEM Domains in Publications Studied

The fourth question of this study is related to which STEM domains the studied publications focus on. During the evaluation, the proportion of domain combinations that appeared and the typical frequency of each domain were analyzed. Interestingly, the proportion of publications focusing on four and two domains was the same, and the number of STEM activities involving three domains was lower regarding all the publications studied. In variations containing two domains still the science domain dominates, which can be explained by the long-standing dominant role of natural sciences (Larkin & Lowrie, 2023). In the last ten years, however, the role of engineering and activity has increased in STEM education, just like the rise of digital technology, making the technology domain more prominent in all domain combinations. In many cases, engineering activities require interdisciplinary knowledge. This may explain why, where teachers wish to engage in this activity, they necessarily involve the other three domains of STEM as well. This means that the increase in the role of engineering domain may also explain the increase in the proportion of domain combinations with four domains.

Our study shows that the domain role of technology was the most decisive, in line with the high proportion of digital technology methods that are dominant among teaching-learning methods. The rising engineering domain has the same proportion as the traditional science domain, while the mathematics domain has the lowest number of occurrences. However, there is no significant difference between the proportions of the individual domains, which shows that the role of the four domains will become more balanced in the future, and the combination of the four domains of science, technology, engineering and mathematics will increasingly prevail in the application of teaching-learning methods and activities even in early childhood, realizing the goals of STEM.

Research Design in Publications Studied

In their literature review on informal STEM learning of children 3-14 years for the period 2015-2021, Alexandre et al. (2022) analyzed the research methods occurring in the literature. They found that quantitative research occurred in the highest proportion, followed by qualitative and then mixed research. Within the basic research methods, the experimental method occurred several times, and the occasional occurrence of quasi-experimental, case study and ethnographic case study methods was also observed. In this study we found the dominance of qualitative basic methods in the publications studied, and the dominance of case study and ethnographic design methods was found in the analysis of STEM teaching-learning methods and activities. The proportion of experimental, quasi-experimental, action research and curriculum intervention methods were smaller. Differences from the results of Alexander et al. (2022) could be caused by that our study evaluated publications on younger children (three-nine years old). This is an age, where it is important for the reliability of the tests that children behave in the most natural environment and in the most natural way possible during their activities and that there should be as little interference as possible. Therefore, case study is more suitable for examining the learning and activities of a child in preschool than an experimental design. Similar reasons explain why observations and video recording tools had the highest proportion in the 29 publications studied. It is also characteristic that the diversity of qualitative study tools is greater than that of quantitative ones. Young children cannot even write, or their self-esteem is not yet developed enough to reliably fill out, for example, a Likert scale questionnaire. Often, the development of their thinking and linguistic expression skills are not yet in harmony, therefore it is more difficult for them to put their thoughts into words. These are all factors that make it difficult to apply quantitative methods and measuring tools in early childhood.

Digital measuring tools had the highest proportion among quantitative measuring tools in the publications studied, although these still need to be improved. This foreshadows the rise of digital technology in measuring and evaluating the impact of early childhood learning processes and activities. However, the application of age-appropriate qualitative methods remains justified.

Objectives, Findings, & STEM Activities in Published Research Works

The objectives and findings of the publications studied can be grouped around different hubs:

1. Some of the stated objectives related to observing the characteristics of STEM education programs, teaching methods, or their impact in a classroom environment (Apostolou, 2023; Bezuidenhout, 2021; Bofferding et al., 2022; Campbell et al., 2018; Chen & Tippett, 2022; Fridberg & Redfors, 2021; Fridman et al., 2020; Kewalramani et al., 2020; Ward et al., 2022). The result of these research works supported the success of STEM education. They proved that children are enthusiastic about STEM activities, and STEM methods and activities help the learning process. An important factor is the role and instructions of teachers in this learning process, and some problems and shortcomings of teachers related to STEM education have also been revealed. In the STEM education process in early childhood, the environment in which the activities take place is also important. Thus, STEM learning needs a well-structured and stimulating classroom that allows free movement and thinking, and a more natural outdoor environment
2. In the second group, the goal was to analyze the impact of a STEM method or activity on cognitive characteristics of children. Speldewinde and Campbell (2022) analyzed the impact of "Bush Kinders" nature education on the engineering and technology abilities of children. Dilek et al. (2020) investigated how children's science process skills, including engineering thinking, develop as a result of STEM inquiry-based learning. The application of the KIBO program in a playful way is another method that has an impact on the development of engineering skills (Sullivan & Bers, 2018).
3. A significant proportion of the publications listed objectives to improve computational thinking or robotics skills and abilities of children (Govind & Bers, 2021; Kanaki & Kalogiannakis, 2022; Liu et al., 2022; Kanaki et al., 2022; Nam et al., 2019). Several publications have focused on analyzing the impact of STEM activities on mathematical abilities (Aldemir & Kermani, 2016; Bofferding et al., 2022; Kermani &; Aldemir, 2015). Publications that aim to develop scientific knowledge and skills through STEM activities can be clearly identified (Adbo & Carulla, 2020; Aldemir & Kermani, 2016; Dejonckheere, 2016; Dilek et al., 2020; Kermani & Aldemir, 2015; Liu et al., 2022). The results showed that the engineering mindset of children developed along with scientific thinking and research skills. Research shows that STEM activities help children apply scientific concepts and incorporate them into engineering activities. The essential role of digital technology in STEM learning has been confirmed by the positive change in the computational thinking skills of children. At the same time, experts acknowledge that digital tools and programs for learning and assessment are not yet perfect and need to be further developed.
4. Some publications also had the objective to study the impact of STEM education on activities (Campbell & Speldewinde, 2022; Campbell et al., 2018; Riniker, 2021; Speldewinde & Campbell, 2022). Research shows that children's implementation of STEM activities is influenced by the learning environment (inspiring, well-organized classroom and natural outdoor environments are inspiring) (Campbell et al., 2018; Speldewinde & Campbell, 2022). According to Riniker (2021), an important element of STEM education is the presence of relevant experience and materials in the learning process. In this learning process, teachers should provide guided experiences for students. At the same time, it is also important that the children feel the importance of their own ideas and views during the activities, which is encouraging for further progress (Campbell & Speldewinde, 2022).
5. Several publications were found that aimed to develop motivation and attitude towards STEM (Bascopé & Reiss, 2021; Dilek et al., 2020; Mitchell et al., 2022; Pattison et al., 2020; Tran, 2018). These publications reported an increase in attitudes towards engineering activities, mindsets, careers, as well as attitudes and motivation towards STEM when using digital technology applications, science inquiry-based learning, and collective activities (involving parents and local communities in STEM activities).
6. Only two publications were found that identified the analysis of the relationship between sustainability education and STEM among the objectives. Liu et al. (2022) included aspects of environmental education in the learning process in addition to learning and applying physical concepts when creating an underwater robot using ModBot tools and software. The children

successfully solved environmental problems as well during the robotics session. Campbell and Speldewinde (2022), when studying the “Bush Kinder” in preschool regarding the relationship between STEM and sustainability, emphasized that guidance and instruction from educators play an essential role in creating this relationship.

7. At the same time, educators working with young children are not yet able to manage this system of relationships properly. Preparing teachers for this is an important task, as one of the priority directions of STEM education in the near future is to find and realize the links between sustainability education and STEM in the early childhood STEM learning process.

The primary goal of our systematic review was to collect publications describing STEM activities in order to give help for STEM pedagogical practice and research. Play occurred among the activities in almost all publications, together with drawing and exercise in many cases, which are basic activities due to the age specialties of early childhood.

In many cases, the activities described were complex design and construction tasks involving all four STEM domains, where engineering activities and thinking were highly emphasized (Apostolou, 2023; Bascopé & Reiss, 2021; Campbell & Speldewinde, 2022; Campbell et al., 2018; Chen & Tippett, 2022; Dilek et al., 2020; Kewalramani et al., 2020; Liu et al., 2022; Pattison et al., 2020; Speldewinde & Campbell, 2022; Sullivan & Bers, 2018; Tippett & Milford, 2017).

Another typical group of activities is the use of digital tools, robotics and programming. The Bee-Bot, KIBO and iPad app are used for developing robotics, programming, digital coding capabilities (Govind & Bers, 2021; Mitchell et al., 2022; Murcia et al., 2020; Sullivan & Bers, 2018), the physical science programming platform for developing computational thinking (Kanaki & Kalogiannakis, 2022), the ModBot for building underwater robots (Liu et al., 2022), the Color Code smart game for examining shape analysis strategies (Bofferding et al., 2022), the littleBits for developing play, creativity and critical thinking (Kewalramani et al., 2020), the TurtleBot robot for sequencing and problem-solving (Nam et al., 2019).

Regarding scientific experiments, we could read about experiments related to water (bubble blowing, sinking, floating) (Chen & Tippett, 2022), comparing quantities (Ward et al., 2022), and experiments aimed at developing a particle approach (crushing leaves, cubes of sugar in a mortar, then observing them under a microscope) (Adbo & Carulla, 2020).

Activities included classroom or outdoor activities aimed at learning about living creatures. In the study of Kanaki et al. (2022), the content of digital play was getting to know animals, while Fridberg and Redfors (2021) also expanded children’s knowledge of living beings, including plants and animals, via the use of digital technology. One of the typical early childhood methods of expanding knowledge about living organisms is storytelling, which was presented in the study of Bascopé and Reiss (2021).

Outdoor activities were rare in the publications studied. Outdoor games in the “Bush Kinder” preschool occurred in a natural environment (building a cubby house, role-playing games) (Speldewinde & Campbell, 2022) or in gardening and playground sessions (Riniker, 2021; Ward et al., 2022).

The efforts of early childhood science education, occurring also in STEM education, to familiarize children with natural and artificial materials through their perception and application were found in the studied publications (Dilek et al., 2020; Fridberg & Redfors, 2021; Fridman et al., (2020); Speldewinde & Campbell, 2022). In these studies, familiarization with materials occurred in a playful way, both in classroom and outdoor settings, sometimes involving digital activities as well.

We also encountered modelling (Campbell & Speldewinde, 2022), activities demonstrating cooking methods, fermentation, dewatering, preservation, crafts and toolmaking (Bascopé & Reiss, 2021), drama games, library use, activities related to music and dance (Riniker, 2021; Sullivan & Bers, 2018).

The range of STEM activities described is wide, offering countless opportunities for the practice of STEM pedagogy according to the purpose of application. What is a clear conclusion based on the studied publications is that children aged three-eight years are able to apply their existing and acquired knowledge and skills in STEM activities in a complex way. They are open, creative and interested in the phenomena and problems of nature, which they approach holistically due to their age. Exploiting and maintaining this age specialty are essential for developing a STEM approach, as it is based on this interdisciplinary, complex system of interaction and knowledge. Thus, this approach should be developed and maintained in early childhood, laying the foundation for STEM education in later ages.

Limits of Research Works & Recommendations

Among the studied research works, mentioning the problems of research methods has the greatest proportion. According to Apostolou (2023), one of the limitations of his study is that the research was conducted in the form of a case study. In his opinion, more research evidence and more new perspectives are needed in early childhood STEM education research. Regarding the inclusion of digital methods in preschool education, he notes that its pedagogical use and use as a research tool are still unexplored. He recommends giving students more opportunities to use creativity and logical thought processes in solving problems in formal school environments.

According to Mitchell et al. (2022), improving interview questions for young children is an important task for the future to reach more correct conclusions. Liu et al. (2022) consider the three-hour learning period they employ for children and then testing it insufficient for reliable conclusions. The study claims that the problem of not using a control group in the research is a methodological error, considering it necessary when testing teaching-learning methods. Reliable results can only be expected even in early childhood after a long period of development work.

Kewalramani et al. (2020) have a similar view, saying that in their study, the gaming experience of four weeks with littleBits was too short for children to learn more advanced, interdisciplinary STEM-centered concepts. The publication also notes that longer-term longitudinal studies should be carried out with as many tools as possible in order to obtain a more complete picture. The need for a wider range of measuring tools is also emphasized by Nam et al. (2019), who measured the computational thinking of children only through sequencing and mathematical problem solving. A more comprehensive measurement of age-appropriate algorithmic thinking was lacking.

Ward et al. (2022) studied how the activity of educators can be traced in the development of STEM reasoning in children, primarily in mathematics. The publication cited as a mistake the failure to study the power dynamics between teachers and children in the classroom. It was also noted that the analysis should have been extend to a more holistic classroom environment.

The research pf Bezuidenhout (2021) on the dialogical reading program for comprehension, feels that there is a lack of further studies on vocabulary development, expansion and conceptualization in children.

Govind and Bers (2021) see the need to reduce and eliminate subjectivity in evaluating findings and processes of robotics projects by developing appropriate evaluation methods. Regarding robotics research, Fridberg and Redfors (2021) believe that future research aims to analyze language use and teaching strategies in the learning process supported by different robots. Sullivan and Bers (2018) believe that teachers are still unprepared for digital learning methods in many cases, and therefore it is a mistake that, for example, in their research, teachers also carried out Solv-Its observations within the framework of the KIBO project for which they were not yet professionally fully trained.

Based on their research Fridman et al. (2020) see problems in a more correct way of evaluating open-ended tasks and in measuring and evaluating metacognitive abilities regarding studies on early childhood STEM education.

According to Tippett and Milford (2017), in addition to the content of STEM activities, the impressions and ideas of children about STEM should also be studied. According to Aldemir and Kermani (2016), the task of the future will be to develop appropriate tools to assess the science and engineering learning process of young children.

Another group of limitations for the research studied is related to institutional and organizational problems in STEM research and education. An important recognition from Apostolou (2023) was the need to integrate STEM education into formal school settings. This is important because it allows children to participate in STEM education more regularly, which can lead to more effective STEM knowledge and skill development. Chen and Tippet (2022) admitted that the limit of their study was that it was only conducted in urban kindergartens. Thus, the range of the sample was limited regarding socioeconomic background. Kanaki and Kalogiannakis (2022) were also dissatisfied with the extent of the expansion of the research, and their problem was limited by a nationwide survey and a lack of investigation on multiple topics, just like Bezuidenhout (2021) who faced the same problem. The latter was also mentioned by Kanaki et al. (2022) as a limitation of their research and they also admitted that when analyzing computational thinking of children, correlation analysis with background factors cannot be omitted. Expanding STEM activities into the home environment was proposed by Dilek et al. (2020) to increase the effectiveness of STEM education. Campbell et al. (2018) call for more effective use of actual STEM integration, while Tran (2018) believe that the content studied should be better aligned with curricular content. Kermani (2015) mentioned excessive administrative control, which hindered the smooth flow of research.

The publications occasionally mentioned that there is little international research on early childhood STEM education (Riniker, 2021). Studies focusing on the relationship between early childhood STEM and sustainability education are the smallest in number (Campbell &; Speldewinde, 2022; Speldewinde & Campbell, 2022). Murcia et al. (2020) cite the lack of literature on digital coding related to creativity development as a problem, while Adbo and Carulla (2020) cite the lack of research on young children's understanding of scientific content.

Some experts cited as a problem that either the studied child population was not large enough (Kanaki et al., 2022; Mitchell et al., 2022) or was not representative (Chen & Tippet, 2022; Kanaki & Kalogiannakis, 2022). What scientists also complained about was the lack of financial support for research (Aldemir & Kermani, 2016; Kermani, 2015).

Overall, the problem in measuring and evaluating the impact of early childhood STEM activities and methods is the lack of appropriate measurement tools (especially quantitative measurement tools) therefore it is necessary to develop them in the near future. Furthermore, a more comprehensive, longer period of development and learning, which provides more reliable results for the development of children. Experimental studies to measure the impact of activities and methods are acceptable only if a control group is used. Teachers should only be involved in measurement and evaluation if they are professionally prepared for it. Almost all studies have suggested that digital measurement tools require further development in measuring the impact of early childhood STEM activities.

Care must be taken to ensure adequate sample size and representativeness. Making the studies more complete requires correlation analysis with background factors. The broader nature of research is provided if the impact of STEM education is studied on as many topics as possible. STEM early childhood research is still insufficient and carries several uncertainties, methodological and organizational problems. Early childhood STEM education itself is not yet widespread enough, and it would be worth to apply it more comprehensively integrated in formal education. Therefore, there is still much to learn about early childhood STEM teaching and learning methods and activities and their impact. This is only possible if scientists publish more and more studies on the subject.

CONCLUSIONS

In this systematic review, 29 publications were analyzed that presented different aspects of early childhood STEM teaching-learning methods and activities over the period 2014-2023. The multi-faceted analysis was intended to help scientists and educators implementing STEM practice. Such detailed listing and systematization of teaching-learning methods and activities have not been encountered in systematic reviews. We filled this gap in this study, providing ideas for scientists and educators interested in early childhood STEM education. The analyses revealed that there is little international literature on the subject, although there has been a significant increase in the number of relevant studies over the last four years. Based on the results of our study, this is largely due to the penetration of digital technology methods into early childhood STEM education.

Research related to robotics, programming and digital evaluation is expected to appear in greater proportion in the near future. Education for sustainability, which is now in focus, appeared only rarely in the publications studied. However, due to its global importance, it is necessary to research the relationship between sustainability education and STEM in early childhood. Due to the immaturity of the topic, besides digital technology, this may be another widely studied area of early childhood STEM education. We have also seen that the studied publications had many research methodological and organizational limitations and uncertainties. It is therefore necessary to develop more measurement tools, which are reliable and valid in the field of impact measurements, especially digital and quantitative measuring instruments. Play is a core element of early childhood STEM education, which can happen in both classroom and outdoor settings. Due to its integrated nature, STEM achieves its goal the most when implemented in a learning environment, where the child perceives reality and the world around him/her in a complex way. The outdoor environment is the most suitable for this, which requires much more activities and sessions in nature (kindergarten, schoolyard, playground, garden, forest, meadow, etc.) than before. We hardly encountered such cases in the publications studied. Thus, it may also be a preferred topic for future research.

Limitation of This Study

This systematic review focused on early childhood teaching and learning methods and activities in STEM education, for which empirical research with specific and detailed activity descriptions were selected for analysis. Since we did not see what activities these studies would focus on when entering search terms and keywords, we sometimes included general and off-topic search terms. This made the search more difficult and even longer in time. Therefore, it is worth providing as many terms as possible that are more specific to the topic (in our case, including the name of the activity, for example), which will result in a more targeted and accurate search for the topic studied.

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APPENDIX A

Table A1. Research objectives of publications (n=29)

Authors	Age	Research objectives
Apostolou (2023)	4-6	Observation of the impact of STEM sessions using BeeBot robots on STEM activity.
Chen and Tippett (2022)	3-6	Presenting design and implementation of project-based inquiry in STEM education in preschool.
Mitchell et al. (2022)	6-7	Measuring the impact of a two-week learning program using KIBO robotics on interest in engineering careers, on the concept of engineering.
Campbell and Speldewinde (2022)	3-6	Studying how interactive, student-centered STEM education influences the investigative and actioned-adapted learning of students in a natural environment.
Speldewinde and Campbell (2022)	3-6	Studying how "Bush Kinders" nature education impacts the engineering and technological activities and abilities of children.
Kanaki and Kalogiannakis (2022)	6-8	Studying the relationship between the development of algorithmic thinking and age in early school age.
Kanaki et al. (2022)	6-8	Explore the algorithmic thinking of students, such as understanding the relationship between computational thinking and content learnt during the environmental science course.
Liu et al. (2022)	5-8	With the help of ModBot tools and software, creating an underwater robot with independent student design and application. Obtaining knowledge about the concepts of underwater movement, perception, buoyancy, ballast and balance, and their application via the activity. Environmental education, solving environmental problems.
Bofferding et al. (2022)	6-9	Shape analysis strategies of early primary school students were studied in the research using the Color Code smart game.
Ward et al. (2022)	4-5	Studying the nature of teacher persistence in early childhood classrooms. Analysis of the role of teacher activity in the development of STEM reasoning of children, primarily in mathematics.
Bascopé and Reiss (2021)	4-10	Studying the impact of STEM education projects on teacher and student STEM attitudes. How community capacities developed through STEM projects help overcome socioecological challenges.
Bezuidenhout (2021)	5-7	Impact assessment of dialogue reading program (DPR) on the comprehension processes of children and also on vocabulary development, expansion, and conceptualization.
Govind and Bers (2021)	7-8	Studying the robotics and programming skills of students with the rubric development of KIBO project.
Riniker (2021)	3-6	The impact of STEM teaching in the preschool classroom. Encouraging STEM thinking.
Fridberg and Redfors (2021)	4-5	Studying the conscious language use of teachers and children during inquiry-based STEM activities.
Murcia et al. (2020)	3-4	Studying how learning digital coding influences the creativity of children using digital technology tools.
Pattison et al. (2020)	3-6	Studying the impact of the family-based engineering education program organized by the Head Start organization on the interest of parents and children in engineering.
Dilek et al. (2020)	5-6	Studying the impact of STEM (especially technological elements) on the motivation of students. Studying scientific research skills during inquiry-base STEM activities, including engineering design.
Adbo and Carulla (2020)	3-5	"Small" in the chemical sense, i.e. the introduction of the concept of a chemical particle in a playful form, followed by the study of its understanding.
Fridman et al. (2020)	5-6	Analysis of the impact of the application of structured and open research in a playful way on the children's scientific interests, metacognitive awareness, self-regulation, and their relationships.
Kewalramani et al. (2020)	3-5	Studying how the introduction of littleBits and related electronic magnetic blocks expands the STEM-focused play and creativity possibilities of children. How littleBits develops the critical thinking of children and expands their interdisciplinary STEM concepts.
Nam et al. (2019)	5-6	Studying the use of TurtleBot, a robot to improve the sequencing and problem-solving skills of children.
Campbell et al. (2018)	4-5	To understand approaches to STEM education, study early childhood play-based STEM practices
Tran (2018)	8-9	The main goal is to analyze the effects of a three-month intervention of computer science (CS) on the perception, attitude, career choices and motivation for CS-assisted learning of primary school students.
Sullivan and Bers (2018)	3-6	Via the application of the KIBO program, the development and measurement of the engineering and technological skills of preschoolers.
Tippett and Milford (2017)	3-6	Studying the commitment to STEM of children as a result of their use of STEM activities and the parents' perception of STEM
Dejonckheere (2016)	5-6	Measuring the impact of inquiry learning on the scientific reasoning skills of students.
Aldemir and Kermani (2016)	3-6	Studying how the application of the STEM model developed within the framework of the Head Start program impacts the development of children's concept of numbers, understanding of science and engineering concepts, and STEM abilities. Also, how effectively teachers can incorporate STEM concepts into their instructions for children.
Kermani and Aldemir (2015)	3-6	The aim of the study is to show how the application of projects and activities integrating these subjects in preschool impacts the knowledge and performance of children in mathematics, science and technology.

Table A2. STEM domains, research methods, & tools & teaching-learning method of publications (n=29)

Authors	Age	STEM domains	Research methods and tools	Teaching-learning method
Apostolou (2023)	4-6	Science technology engineering mathematics	Qualitative: case study, classroom & observation	Project-based inquiry & robotics
Chen and Tippett (2022)	3-6	Science technology engineering mathematics	Qualitative: case study classroom observation, teacher structured interview, & research diary	Project-based inquiry
Mitchell et al. (2022)	6-7	Engineering technology	Mixed curricular intervention Qualitative: student semi-structured interview Quantitative: Draw an engineer test & pre/post-test	Robotics, digital play-based learning, & programming
Campbell and Speldewinde (2022)	3-6	Science technology engineering mathematics	Qualitative: ethnographic design	Play-based learning in nature modelling
Speldewinde and Campbell (2022)	3-6	Science technology engineering mathematics	Qualitative: ethnographic design	Play-based learning in nature
Kanaki and Kalogiannakis (2022)	6-8	Technology science	Quantitative: Physical science programming platform, & open end tasks	Digital play-based learning
Kanaki et al. (2022)	6-8	Technology science	Quantitative: Physical science programming platform & open-end tasks	Digital play-based learning, programming
Liu et al. (2022)	5-8	Engineering science	Mixed-action research Qualitative: videorecording, student semi-structured interviews, & drawing tasks Quantitative: pre/post-test for knowledge of Underwater Robot	Robotics & digital play-based learning
Bofferding et al. (2022)	6-9	Mathematics engineering	Qualitative: case study creation of a double layered puzzle-plan in the Color Code puzzle game, student structured interviews	Play-based inquiry in classroom
Ward et al. (2022)	4-5	Mathematics engineering	Qualitative: case study	Inquiry-based learning
Bascopé and Reiss (2021)	4-10	Science technology engineering mathematics	Qualitative: ethnographic design	Project-based inquiry
Bezuidenhout (2021)	5-7	Science technology engineering	Qualitative: case study teacher, parent, and student interviews	Digital play-based learning
Govind and Bers (2021)	7-8	Technology engineering	Quantitative: action research: KIBO Project Rubric	Robotics, digital play-based learning, programming
Riniker (2021)	3-6	Science technology engineering mathematics	Qualitative: ethnographic design	Play-based inquiry in classroom
Fridberg and Redfors (2021)	4-5	Science technology engineering mathematics	Qualitative-case study video recording, classroom observation	Robotics digital play-based learning, programming
Murcia et al. (2020)	3-4	Technology science	Qualitative: experimental, digital photos about the activities, classroom observations	Robotics, digital play-based learning
Pattison et al. (2020)	3-6	Engineering	Qualitative: ethnographic design	Engineering activities
Dilek et al. (2020)	5-6	Science technology engineering mathematics	Qualitative: action research, classroom observations, video recording, pre/post semi-structured interviews with children	Inquiry-based learning
Adbo and Carulla (2020)	3–5	Science technology engineering mathematics	Qualitative: visual ethnography design	Play-based inquiry in classroom
Fridman et al. (2020)	5–6	Science	Mixed case study Qualitative: classroom observation, student structured interview. Quantitative: analyzing verbal and non-verbal replies and reactions using a coding scheme	Inquiry-based learning
Kewalramani et al. (2020)	3–5	Science engineering technology	Qualitative: case study, classroom observations, teacher semi-structured interviews, student artworks, video recording	Robotics, digital play-based learning

Table A2 (Continued). STEM domains, research methods, & tools & teaching-learning method of publications (n=29)

Authors	Age	STEM domains	Research methods and tools	Teaching-learning method
Nam et al. (2019)	5-6	Mathematics technology	Mixed curricular intervention Qualitative: classroom observation Quantitative: tests to measure sequencing and problem-solving skills	Robotics, programming, digital play-based learning
Campbell et al. (2018)	4-5	Science technology engineering mathematics	Qualitative: case study teacher semi-structured interviews, classroom observations	Play-based learning in nature
Tran (2018)	8-9	Mathematics technology	Mixed action research Quantitative: student pre- and post-tests Qualitative: student interviews	Digital play-based learning
Sullivan and Bers (2018)	3-6	Engineering technology	Mixed quasi-experimental Quantitative: Solve-its assessment. Engineering is elementary science and attitudes assessment (EiE) Qualitative: Teacher structured interview	Robotics, digital play-based learning, programming
Tippett and Milford (2017)	3-6	Science technology engineering mathematics	Mixed case study Quantitative: parent questionnaires Qualitative: classroom observation, semi-structured interview for teachers, photo of the artefacts of children, video recordings	Project-based inquiry
Dejonckheere (2016)	5-6	Science mathematics	Qualitative: experimental video recording student structured interviews	Inquiry-based learning
Aldemir and Kermani (2016)	3-6	Science technology mathematics engineering	Mixed quasi experimental Quantitative: Mathematic skills: Test of Early Mathematics Ability-3 (TEMA-3) Qualitative: Science skills: Analyzing Video recording, structured interviews for teachers, document analysis session schedule of teachers	Project-based inquiry
Kermani and Aldemir (2015)	3-6	Science mathematics technology	Mixed quasi experimental Quantitative: Mathematic skills: Early Mathematics Ability-3(TEMA-3) Qualitative: Science skills: Analyzing video recording, structured interview for teachers, document analysis session schedule of teachers.	Project-based inquiry

Table A3. Learning activities of publications (n=29)

Authors	Age	Learning activities
Apostolou (2023)	4-6	Based on the short film "The Red Balloon", dialogue, raising a problem, launching activities. Planning a small town, measurements, expression of distances. Drawing, Bee-Bot programming.
Chen and Tippett (2022)	3-6	Aged 3–4 years: experiments with water (blowing bubbles, sinking and floating). Aged 4–5 years: car powered by wind, designing spinning tops from different material. Aged 5–6 years: designing paper airplanes, building boats for animals.
Mitchell et al. (2022)	6-7	Based on the integrated STEM curriculum unit children are involved in programming an alarm using a KIBO robot.
Campbell and Speldewinde (2022)	3-6	Outdoor observation, modelling phenomena
Speldewinde and Campbell (2022)	3-6	Activities with natural materials and tools (e.g., cubby house building), play in nature, field activities, role-playing games.
Kanaki and Kalogiannakis (2022)	6-8	Environmental study course to get acquainted with the feeding habits of animals and the application of knowledge. Physical science programming platform, digital game
Kanaki et al. (2022)	6-8	Getting to know animals in a digital, playful way, puzzle
Liu et al. (2022)	5-8	Design and construction of underwater robots, ModBot tools and software application, design, implementation, problem solving.
Bofferding et al. (2022)	6-9	Assembling geometric form ensembles (layering) and disassembling, repairing them
Ward et al. (2022)	4-5	Gardening, playground design, problem solving, comparing quantities (with the help of spinner/wheel of fortune, and balance) experiments, games.
Bascopé and Reiss (2021)	4-10	Health and the human body: healing/medicinal plants. Traditional dishes and cooking methods: fermentation, dehydration, preservation. Crafts and tool-making: coloring wool with plants, goldsmith's work. Ecosystem and agriculture: tales about characteristic living creatures, soil types, sowing forms, reading the signs of weather.
Bezuidenhout (2021)	5-7	Dialogue reading program (DRP) for young children, games
Govind and Bers (2021)	7-8	KIBO Project Rubric, programming
Riniker (2021)	3-6	Drama, games, arts, library, exploration, music, exercise, cooking and technology, outdoor games at a playground.
Fridberg and Redfors (2021)	4-5	Work with the materials, objects and living creatures of nature. Blue-Bot robotics, programming.
Murcia et al. (2020)	3-4	Robotics, Bee-Bot game and iPad app, the life and living conditions of a bee
Pattison et al. (2020)	3-6	Building a tower to protect a hen from a fox up to 1 meter high; creating a safe path that will help a "mouse" (i.e. a ping-pong ball) escape from a cat; designing and testing various bubble sticks and bubble solutions for children for use in a bath; designing a comfortable nest to accommodate a baby bird.
Dilek et al. (2020)	5-6	Construction of bridges, parachutes, aircrafts, ships from different materials
Adbo and Carulla (2020)	3-5	Observation, experiment. Developing a particle approach. The introduction of the scientific concept of "small" in two steps. First, crushing leaves, cubes of sugar in a mortar, studying them with a magnifying glass, microscope (aged 3–4 years). Later, as a second step (the same children at the age of 5), they participated in about 20 minutes of activities (wood, leaf, water, from a whole shape to molecules) that included computer video animations twice a week.
Fridman et al. (2020)	5-6	Structures and open research with various everyday material
Kewalramani et al. (2020)	3-5	Playing with littleBits electronic magnetic blocks. Building a robot city, while using scientific concepts (e.g., solar panels, energy, batteries, electricity, wires, magnetic links, and circuits)
Nam et al. (2019)	5-6	Sequencing and problem solving, independent thinking, thinking aloud, teamwork, TurtleBot programming
Campbell et al. (2018)	4-5	Indoor and outdoor sessions. E.g. designing and building a cubby house, observing and discussing the weather, extracting tree sap with wooden sticks. Balancing on a tree trunk.
Tran (2018)	8-9	Computer aided practical classroom activities, experiments.
Sullivan and Bers (2018)	3-6	7-week STEAM KIBO robotics curriculum: "Dances from Around the World", Building dancing robots
Tippett and Milford (2017)	3-6	Observation, examination, drawing, construction in the following topics: Birdhouse, Sinking and Floating
Dejonckheere (2016)	5-6	Explore and observe with magnets, magnifying glasses, swings, keys and padlocks, scales, slopes, music glasses, colored filters, gears, shadows, screws, rubber rings, falling objects.

Table A4. Findings of publications (n=29)

Authors	Age	Findings
Apostolou (2023)	4-6	Students' enthusiasm for STEM activities grew. They applied their conceptual knowledge and STEM skills in a creative, integrated way.
Chen and Tippett (2022)	3-6	Project-based learning can be applied successfully in preschool. Children are motivated in PBI activities.
Mitchell et al. (2022)	6-7	Students' perception of engineering improved. Girls showed greater interest in engineering. It is important to develop gender-sensitive STEM curricula.
Campbell and Speldewinde (2022)	3-6	Regarding action-adapted learning and sense of agency, it is important for children to feel the importance of their own ideas and views. Teachers need to improve their understanding of the interactions between STEM and sustainability.
Speldewinde and Campbell (2022)	3-6	The uniqueness of the environmental conditions prompted children to find creative solutions. They were able to cooperate socially, build together, and correct their activities. Their play is characterized by the presence of narratives.
Kanaki and Kalogiannakis (2022)	6-8	Algorithmic thinking skills are correlated with age during the first two years of primary school.
Kanaki et al. (2022)	6-8	There is a positive correlation between the algorithmic thinking skills of first and second grade students and their understanding of the knowledge obtained through the Environmental science course.
Liu et al. (2022)	5-8	The sessions were successful in applying knowledge of physical concepts, solving environmental problems and designing devices. In the age studied, it is important to approach and apply robotics in a playful way, clarifying the basic concepts, and to consider the emotional, mental and social characteristics of children.
Bofferding et al. (2022)	6-9	First grade students performed better in the embedding task compared to third grade students. Results improved in both grades for the second game organized within 2 months. Helping students focus on substructures can foster finding an effective solution.
Ward et al. (2022)	4-5	Teacher persistence helps the development of the STEM reasoning skills of young students.
Bascopé and Reiss (2021)	4-10	STEM elements and the local community were involved in five topics involved. Children and teachers felt more useful by the end of the year-long projects. Children experienced the usefulness of natural sciences and the involvement of local communities helped to increase acceptance of the work of schools.
Bezuidenhout (2021)	5-7	The success of the Dialogue reading program depends on three interrelated elements: 1) scientific research and theories; 2) an iterative participation approach; 3) systematic application of existing examples of relevant learning materials.
Govind and Bers (2021)	7-8	KIBO project-based assessment is just one way to help children understand KIBO knowledge. The KIBO project requires further development.
Riniker (2021)	3-6	Incorporating STEM into the early childhood classroom has fostered learning through relevant experience and materials. Teachers have to offer guided experiences.
Fridberg and Redfors (2021)	4-5	The coding of recorded communication shed light on the occurrences and possible pitfalls of the use of representations related to abstractions, the contextualized and decontextualized language use of teachers.
Murcia et al. (2020)	3-4	The sequence of activities is important for stimulating the creativity of children. Testing the developed framework for measuring creativity needs further studies.
Pattison et al. (2020)	3-6	The study of the development of family-level interest highlighted three main aspects: 1) parents' awareness, knowledge and values towards engineering; 2) the family's commitment to engineering; 3) use of the technical design process in the family to a greater extent.
Dilek et al. (2020)	5-6	After the sessions, they were able to articulate why they built the different subjects and turned to natural sciences as an exciting field with enthusiasm. The emergence of science process skills and engineering thinking during the activities was observed.
Adbo and Carulla (2020)	3-5	A complete understanding of the meaning of chemical concepts in early childhood depends on how successful teachers are in finding appropriate activities. With the help of computer animations, they understood from large to atoms that there is also a world that cannot be perceived with the naked eye.
Fridman et al. (2020)	5-6	During the open research, they were much more active, they were able to ask questions bravely, they were enthusiastic and interested even without instructions. They like to be part of scientific observations and experiments, they are able to make hypotheses and predictions.
Kewalramani et al. (2020)	3-5	Children gained self-confidence in relation to scientific and engineering work. Their scientific vocabulary, interpersonal skills developed. They began to conduct independent testing, practicing scientific experimental design. They learnt via experiencing.
Nam et al. (2019)	5-6	Children who took part in the robotics project performed better in sequencing and problem-solving tests.
Campbell et al. (2018)	4-5	In indoor environments, children's learning depends on the design of the environment and the specific activities developed by the teacher. Regarding the outdoor environment, it is more efficient if it is not very developed, it has objects/spatial elements as close to natural as possible.
Tran (2018)	8-9	Engaging with Computer Science content early is key from primary school onwards. In this way, children learn how lessons relate to other curricular areas and to their current and future lives. CS has had a positive impact on children's learning with a computer.
Sullivan and Bers (2018)	3-6	Children were successful in learning basic programming concepts. Teachers have successfully supported a collaborative and creative environment.

Table A4 (Continued). Findings of publications (n=29)

Authors	Age	Findings
Tippett and Milford (2017)	3-6	Teachers find STEM education useful, as do parents. The children took an active part in the activities. STEM should be part of early childhood education.
Dejonckheere (2016)	5-6	The program facilitated the development of the exploratory thinking of the those taking part in the experiment.
Aldemir and Kermani (2016)	3-6	Children's conceptual knowledge and understanding, engineering skills developed. iPad use has increased interest in STEM activities. Teachers have also made progress in incorporating STEM concepts into instructions.
Kermani and Aldemir (2015)	3-6	In the experimental group, the mathematical concepts and abilities of children showed significant improvement compared to the control group. Their interest in science and Googling' to search technology grew.

Table A5. Limits of studies (n=29)

	LIR	SS	SR	RM	TO	FS
Apostolou (2023)				×	×	
Chen and Tippet (2022)			×		×	
Mitchell et al. (2022)		×		×		
Campbell and Speldewinde (2022)	×					
Speldewinde and Campbell (2022)	×					
Kanaki and Kalogiannakis (2022)			×		×	
Kanaki et al. (2022)		×			×	
Liu et al. (2022)				×		
Ward et al. (2022)				×	×	
Bascopé and Reiss (2021)						
Bezuidenhout (2021)				×	×	
Govind and Bers (2021)				×		
Rimiker (2021)	×					
Fridberg and Redfors (2021)				×		
Murcia et al. (2020)	×					
Dilek et al. (2020)					×	
Adbo and Carulla (2020)	×					
Fridman et al. (2020)				×		
Kewalramani et al. (2020)				×		
Nam et al. (2019)				×		
Campbell et al. (2018)					×	
Tran (2018)					×	
Sullivan and Bers (2018)				×	×	
Tippett and Milford (2017)				×		
Aldemir and Kermani (2016)				×		×
Kermani and Aldemir (2015)					×	×

Note. LIR: Lack of international research; SS: Sample size; SR: Sample representativity; RM: Research methods; TO: Teaching organization; & FS: Financial support