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Research on STEM in Early Childhood Education from 1992 to 2022: A Bibliometric Analysis from the Web of Science Database

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Abstract: STEM education is an irreplaceable movement of educational systems across the globe in the 21st century. Both Pre-K, K-12, and higher education institutions consider STEM as an innovative approach to integrate and reform the teaching and learning processes. The purpose of this paper is to examine the development of studies on STEM in the Early Childhood Education context from 1992 to 2022. We investigated a dataset of 308 scholarly works from the Clarivate Web of Science database and figured a diversified collection of research focuses on topics such as children's readiness, outcomes, teachers' competency in designing and implementing STEM activities, and the role of computational thinking and robotics. The findings of this paper revealed the dominant contribution of researchers from the USA regarding research quantity and impact, as well as their collaborations with researchers from Western countries. In addition, we also figured out the top influencing authors, documents, and journals as a suggestion for scholars who are new to this topic. However, we would like to note that our findings depended on the quality of the imported database from the WoS system, which covers top-tier journals only.

Keywords: *Bibliometric, early childhood education, STEM education, Web of Science.*

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Introduction

In the context of the Industrial Revolution 4.0, the transition toward science, technology, engineering, and math (STEM) education is not only a trend but also a strategy in many countries worldwide, regarding either preschool education or higher stages (Ata Aktürk & Demircan, 2017; DeJarnette, 2018; Ha et al., 2020). STEM education has the goal of emphasizing the integrated use of technologies to develop students' higher-order abilities (Zhan et al., 2022).

However, researchers also noticed several issues related to STEM education cooperating with teachers and students. Firstly, preschool teachers tend to be less confident than P-12 teachers in implementing STEM education because they have been less trained to teach a specialized subject in STEM fields. As a result, preschool teachers often underestimate their abilities and expose negative tendencies toward implementing STEM activities or projects (Jamil et al., 2018). For example, they allocate reduced instructional time to teach STEM-specific material to their students. (DeJarnette, 2018). Secondly, although early math skills have the most significant predictive power among subjects (Duncan et al., 2007), there is also evidence of preschoolers' low readiness toward science projects. Therefore, it is difficult for preschool teachers to integrate Math, Science, Engineering, and Technology content into early childhood education (ECE) activities. In addition, Fleer (2021) also pointed out the issue of gender inequality in STEM education in the early childhood context. According to Su and Yang (2023), STEM education targeting children between the ages of 3 and 8 has notably garnered

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less focus. The escalating scholarly consensus regarding the significance of fostering STEM education within the domain of ECE is becoming increasingly evident (McClure et al., 2017).

Although several works have been conducted to review studies about STEM in ECE (Ata Aktürk & Demircan, 2017; Su & Yang, 2023; Wahyuningsih et al., 2020), there is a lack of research that reveals the complex structure of research and collaborations on this topic, due to the limitations of traditional literature review methods. Specifically, the recent research conducted by Su and Yang (2023) also employs data from the Web of Science (WoS) and the bibliometric analysis method; however, it is our contention that relying solely on STEM keywords, as opposed to encompassing both STEM and science, technology, engineering, math, and art (STEAM), could potentially overlook certain pivotal documents within the landscape of research pertaining to this subject within ECE.

The current research aims to explore the prevailing scholarly pattern concerning STEM in ECE literature. It endeavors to delineate specific facets of STEM within the realm of ECE literature through the utilization of bibliometric and co-citation methodologies, employing an analysis of the Web of Science (WoS) database. This endeavor is poised to enhance comprehension of the existing landscape of early STEM education publications and proffer prospective avenues for research in the domain of STEM in ECE. Hence, the present investigation endeavours to elucidate the four research questions (RQ):

RQ1: What is the geographical distribution and growth trajectory of the literature on STEAM in ECE?

RQ2: Which journals and authors have exerted the most notable influence within the primary subject areas of literature related to STEAM in early childhood education?

RQ3: What are the most researched keywords, themes, and topics in the knowledge base of STEAM in ECE over time?

RQ4: What are the recent developments and trends in this research field?

Literature Review

STEM education is an interdisciplinary approach to learning that integrates academic principles from the domains of Science, Technology, Engineering, and Mathematics with practical, real-world applications (Moore & Smith, 2014). In the current literature, STEM in ECE receives less attention than at other levels of education (Su & Yang, 2023). Numerous specialists emphasized the importance of providing STEM education to young children (Bybee & Fuchs, 2006; Helm & Katz, 2016; Tao, 2019). STEM education enhanced the computational thinking abilities of children (Bers, 2020; Leonard et al., 2016) and problem-solving skills (Akcay Malcok & Ceylan, 2022), and enhanced children's self-efficacy (Leonard et al., 2016); through diverse activities, children can learn STEM subjects (Wan et al., 2021) and when children start to understand STEM concepts and skills during preschool, they can delve into more intricate and abstract ideas when they reach primary school (Geary et al., 2013). Previous research revealed that STEM education amalgamates interconnected disciplines into a single lesson, drawing on the connections between the subjects and real-world issues (Moore et al., 2014), encouraging preschoolers' involvement in an exciting way to improve their attitude toward the learning process, enhancing their creativity, engagement, problem-solving skills, teamwork skills, and communication ability (Mengmeng et al., 2019; Peng, 2020).

The application of STEAM-related activities in Early Childhood Education (ECE) has attracted the attention of researchers worldwide since 1992, when the term STEAM had not been defined yet. STEAM refers to science, technology, engineering, arts and mathematics, which relates to STEM (Kang, 2019; Marín-Marín et al., 2021). In other words, the term STEAM is derived from STEM (Maeda, 2013), which emphasizes creativity and design-thinking by generating a logical fit for the arts-related activities and mindset to be incorporated into the STEM fields (Robelen, 2011; Sharapan, 2012). Additionally, numerous investigations have determined that child-centered learning, active participation, diverse resources, peer collaboration, and teacher guidance should form the foundation of STEM/STEAM curriculum activities (Aldemir & Kermani, 2017; Morrin & Liston, 2020).

The scholars additionally demonstrate that within the realm of ECE, educators exhibit a substantial inclination towards engaging in professional advancement workshops encompassing domains such as robotics, engineering, programming, and pedagogical methodologies (Bers et al., 2013). Moreover, early childhood educators have a crucial role in cultivating children's curiosity and enthusiasm for STEM education (Kim et al., 2015; Simoncini & Lasen, 2018).

However, researchers also noticed several issues related to STEM education cooperating with teachers and students. Firstly, preschool teachers tend to be less confident than P-12 teachers in implementing STEAM/STEM education because they have been less trained to teach a specialized subject in STEM fields. As a result, preschool teachers often underestimate their abilities and expose negative tendencies toward implementing STEM activities or projects (Jamil et al., 2018). For instance, they spend less time teaching STEM-specific content to their students (DeJarnette, 2018). Secondly, although early math skills have the most significant predictive power among subjects (Duncan et al., 2007), there is also evidence of preschoolers' low readiness towards science projects. Therefore, it is difficult for preschool teachers to integrate Math, Science, Engineering and Technology contents into ECE activities. In addition, Fleer (2021) also pointed out the issue of gender inequality in STEM education in the early childhood context. Furthermore, preschool

STEM activities could encourage parental involvement, which significantly influences children's interests in STEM fields (Salvatierra & Cabello, 2022).

The significance of STEM education has generated interest, leading to an upsurge in scientific research dedicated to the subject (Zeidler, 2016). Numerous scholarly works employ bibliometric analysis to scrutinize STEM education, aiming to discern the overall configuration of scientific knowledge and the communicative structure within the field. Among these works, some researchers conduct analyses based on data derived from the Web of Science (Gil-Doménech et al., 2020; Maphosa et al., 2022; Özkaya, 2019; Yu et al., 2016), while others utilize data from Scopus (Jamali et al., 2022; Le Thi Thu et al., 2021; H.-H. Pham et al., 2021; P.-T. Pham et al., 2022; Phan et al., 2022). The distinctions in these studies arise from the selection of different subjects or educational levels as well as the manner in which the research period and geographical scope are delimited.

Methodology

In this study, bibliometric analysis, which involves a quantitative assessment of scientific work, was employed to portray the evolution of scientific knowledge on STEM in ECE. Bibliometric analysis is a commonly used technique to analyze scientific publications in a certain field to discover research trends, author influence, documents and scientific journals (Chiu & Ho, 2007; Hallinger & Kovačević, 2021; Nguyen et al., 2023). This method has also been used for various fields such as scientific communication (Nguyen et al., 2023; Pham-Duc et al., 2022; Trinh et al., 2020), educational leadership and management (Hallinger & Kovačević, 2021; P.-T. Pham et al., 2022), life-long learning (Do et al., 2021), international student (Ha et al., 2020; H.-H. Pham et al., 2021), and STEM education or mathematics education (Phan et al., 2022; Zhan et al., 2022). Consequently, a bibliographic analysis is an appropriate method to employ in addressing our research queries.

Although the argument of Su and Yang (2023) is very reasonable about choosing keywords while studying STEM in ECE, this study searched for documents with either STEM or STEAM keywords for bibliographic analysis. For example, there are documents that mentioned STEAM as a notable research trend in STEM education, but the keyword "STEAM" does not appear in the "keywords" section (Sırakaya & Alsancak Sırakaya, 2022). Many research works on this topic have listed two keywords, "STEM", and "STEAM", simultaneously (Ng et al., 2022), but there are works that do not have any keywords as STEM or STEAM but have these words in the title of the article (Lindeman et al., 2014). There are works where the article's title does not have the word STEM, but the keyword has it (Jamil et al., 2018). Therefore, to ensure that we can find the most documents on this topic, we used a search algorithm either "STEM" or "STEAM", to query the database.

This research extracted data from the Clarivate Web of Science (WOS) database, which is one of the most comprehensive academic databases across the globe. On 18 July 2022, the researchers conducted a Boolean search string on the WOS database as follows:

(TS=(STEAM) OR TS=(STEM))
AND (TS=(early childhood education) OR TS=(kindergarten) OR TS=(preschool))

The above search structure came up with 389 articles. Following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) process, as stated by (Moher et al., 2009), the authors eliminated five reviews and editorial notes as well as 76 articles from non-related journals. Finally, the screening process came up with 308 papers (Figure 1).

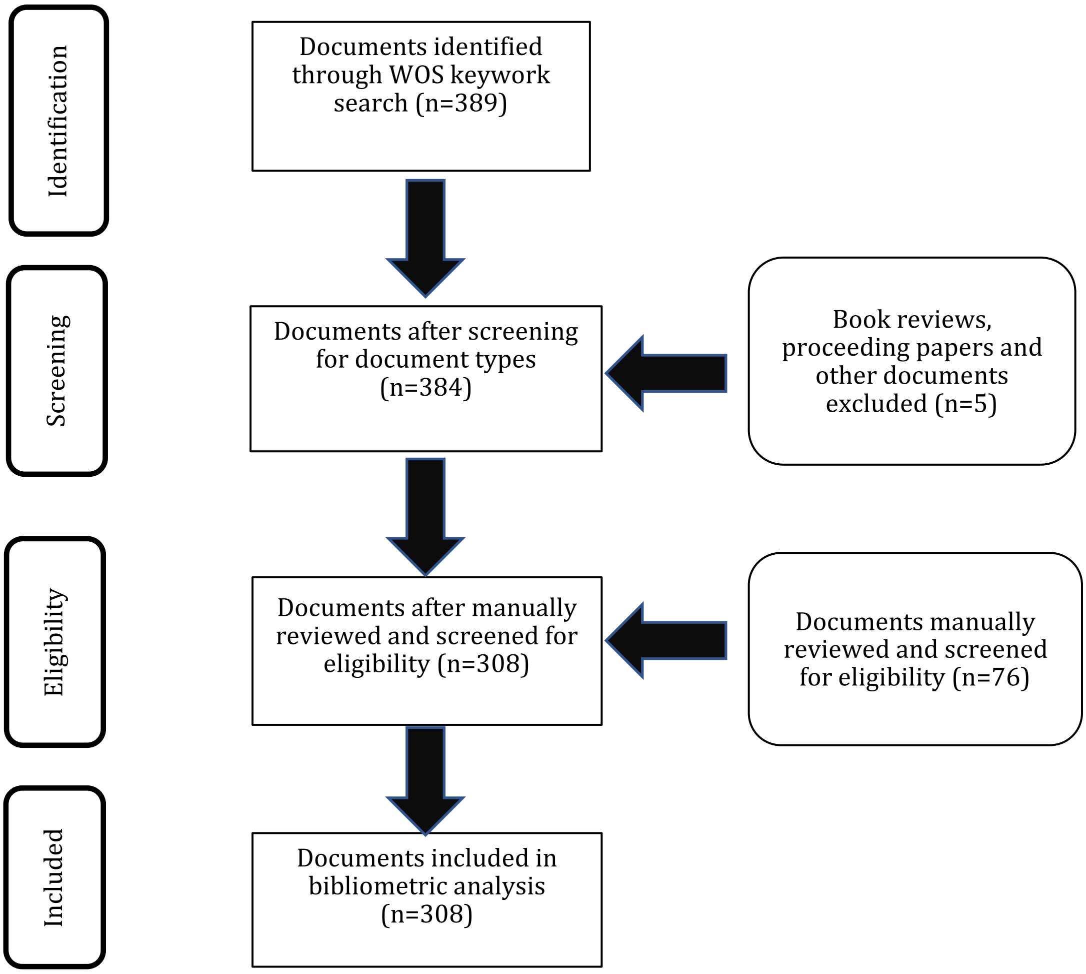

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow Diagram Detailing Steps to Identify and Screen

The researchers exported the metadata of 308 articles to excel and plain text formats, including authors' full name, affiliation and country, title, journal, authors' keywords, journal's keyword, abstract, citation, and references. The plain text file was analyzed using VOS viewer (version 1.6.18) (Van Eck & Waltman, 2010) to create large-scale bibliometric maps for co-authorship, co-occurrence, and co-citation analyses. Furthermore, extensive scientific cartography assessments were conducted utilizing R (version 4.2.1). The VOS (Visualization of Similarities) tool, conceived less than two decades ago, was designed for the analysis and visualization of patterns inherent in data (Van Eck & Waltman, 2007). This software constructs co-occurrence networks of important terms (keyword, author, organization, journal or source, and country) extracted from a corpus of the scientific literature such as WoS, Scopus or Google Scholar (Bukar et al., 2023; Van Eck, & Waltman, 2010; 2018). In this research, the VOSviewer software will conduct the following analyses: 1) co-authorship analysis, 2) co-citation analysis of keywords, authors, and documents, and 3) co-occurrence keyword analysis. The R Biblioshiny package was used to do the thematic analysis of keywords plus (Makkizadeh & Sa'adat, 2017) and create a Sankey diagram visualization of the flow of research focused on STEM in ECE.

Results

The Geographical Distribution and Growth Trajectory of the Literature on STEAM In ECE

Figure 2 illustrates the yearly publication counts related to STEM education in ECE in the timespan 1992 - 2022. This trajectory can be divided into two periods: gradual growth from 1992 to 2012 (39 publications), and then rose dramatically from 2013 to 2022 (240 publications), which is 5.5 times more than the number of articles in the previous stage. Even though this dataset was extracted on 18 July 2022, the number of publications indexed in 2022 is higher than in 2019, not too far from the total production of 2021. This remarkable growth indicates that the topic of STEM in ECE has received interest from researchers since 2013, and until now, scientists are continuing to add more works.

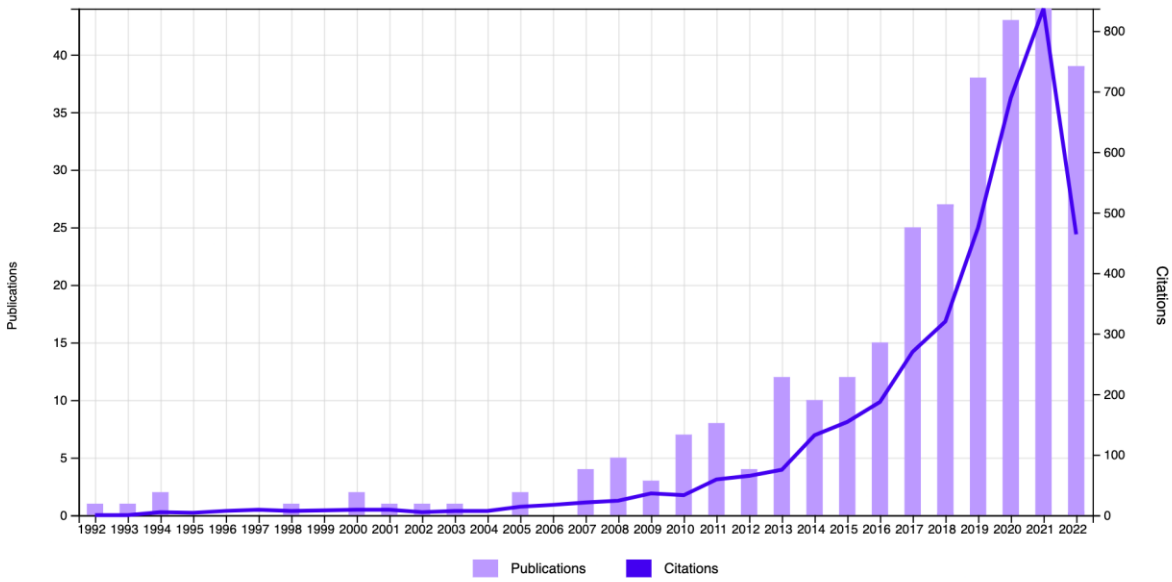

Figure 2. STEAM in ECE Citation Reports (1992 - 2022)

Contributions by Countries

Regarding the sources of publications within the WOS database, there were involvements of scientists from 47 countries in the knowledge base of STEM in ECE from 1992 to 2022. In particular, Figure 3 indicated that twelve countries had more than five research on this topic. Each of the remaining 35 countries has fewer than four papers and did not earn a spot in this table. Notably, the USA was the top contributor with 128 articles, far exceeding other countries, and accounted for 41.55% of works within this dataset. The second tier includes Australia, Spain, and Turkey, with 22, 20, and 17 publications. Each of the eight countries in the third tier has less than ten publications. However, most of the articles in the USA were Single Country Publication (SCP), and there were only four articles in which authors from the USA collaborated with authors from other countries (MCP – Multiple Country Publication), accounting for 0.03%. The two countries having the most MCP articles were China and the United Kingdom, with the same output of five collaborated works (MCP ratio of 0.55%), which is higher than their own SCP (4 papers from each country).

According to this database, the studies on STEM in ECE focused mainly on the American, Australian, and European contexts. Within the top 12, China and Israel were two Asian representatives, but their total number of works is only 14. Out of this top 12, there were Indonesia and Malaysia, two Southeast Asian representatives that contributed three and one article(s), respectively.

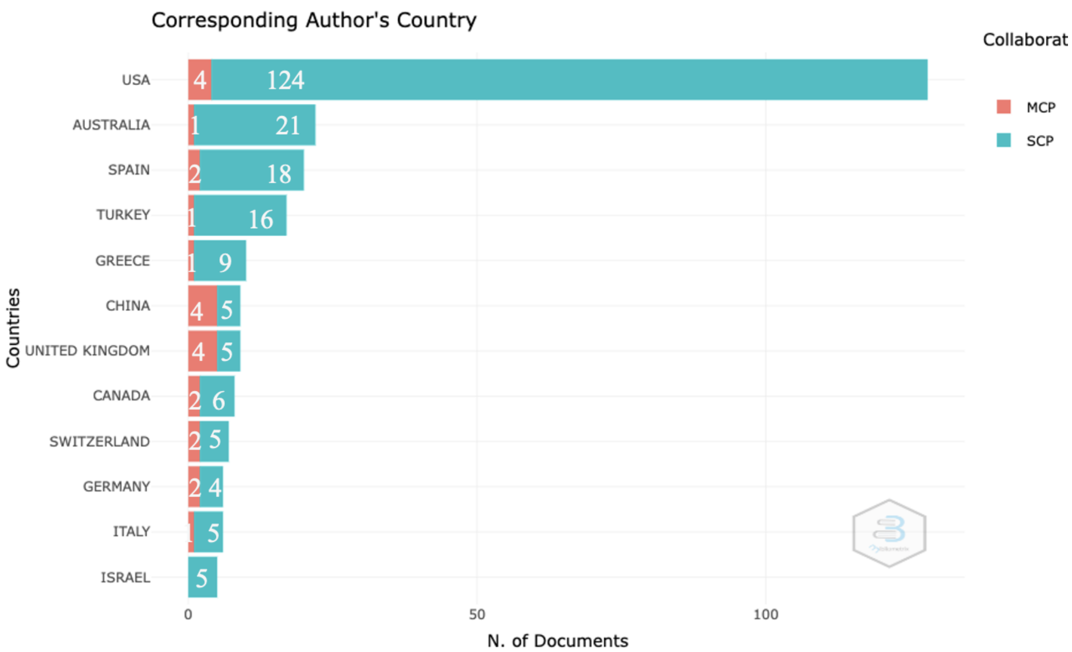

Figure 3. Top Countries' Contributions on STEM in ECE From 1992 to 2022

(MCP: Multiple Countries Publication; SCP: Single Country Publication)

Collaboration by Countries:

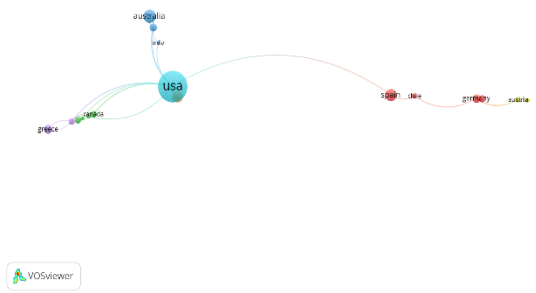

Figure 4a. Country Collaboration Network Map

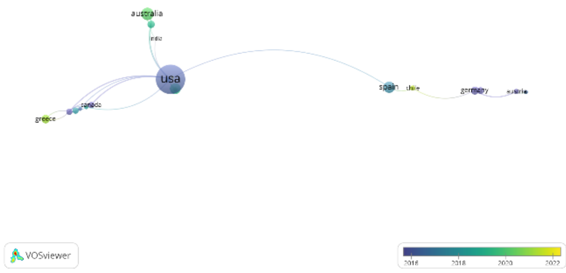

Figure 4b. Country Collaboration Overlay Map

Countries' collaboration on STEM/STEAM education research in preschool is visually mapped in figure 6a. The link's width indicates the level of collaboration, while the size of the node corresponds to the number of publications from those countries. Different colors identified the seven major clusters. According to this dataset of 308 articles from the WOS database, the USA has had the most international cooperation with other countries in STEM/STEAM education for preschool children since very early, before 2016. Regarding 135 publications from the USA, there were only four articles that American researchers collaborated with foreign colleagues (as mentioned in figure 3). However, there were a total of 17 links, indicating the USA's collaborations with 11 other countries and territories. The second biggest node belongs to the Republic of China, which collaborated with nine countries to publish five MCP. The UK also has five MCP but collaborated with 6 countries only.

Figure 6b indicates the overlay timeline of each country's first publication on STEM in ECE. The pioneering countries are colored dark blue, while the latecomers are shown in yellow. While North American and European countries started to collaborate on this topic very early, South American and Asian countries triggered more and more shared projects since 2018. Overall, it can be seen that STEM/STEAM education for preschool children is getting more and more attention from both western and eastern countries.

The Most Significant Impact Journals and Authors

Regarding the aims to determine top journals' impact, the researchers considered various filters and came up with table 1. We favored the H-index as the first filter to identify journals with stable and uniform quality. Then, total citations are considered to determine the most influential journal in the respective h-index group. Finally, based on the number of articles and their first year of publication on this topic, the number of average citations per year can demonstrate each journal's average impact through the years.

Table 1. The 12 Most Prolific Journals in the Field of STEM Education in Early Childhood Education, as Determined by H-Index, Total Numbers of Citations and Total Numbers of Publications

No	Source	h-index	TC	Articles	PY_ start	Citation/article
1	Early Childhood Education Journal	6	213	11	2013	19.36
2	International Journal of Technology and Design Education	4	234	5	2013	46.80
3	Technology Knowledge and Learning	4	64	5	2017	12.80
4	Early Child Development and Care	4	35	9	2011	3.89
5	Research in Science Education	4	25	4	2020	6.25
6	Early Education and Development	3	97	4	2015	24.25
7	Frontiers in Psychology	3	95	6	2013	15.83
8	Journal of Information Technology Education-Innovations in Practice	3	62	3	2013	20.67
9	PLOS ONE	3	30	3	2015	10.00
10	Sustainability	2	57	4	2018	14.25
11	Journal of Early Childhood Research	2	41	4	2016	10.25
12	Education Sciences	2	19	12	2020	1.58

Within this dataset, 210 journals published 308 articles on STEAM/ STEM in ECE, with an average of 1.47 articles per journal. The top 12 journals in table 1 must ensure two requirements: a minimum h-index of two and at least 19 citations. These 12 journals have published 70 articles – accounting for 22.73% of the total articles within this database. However, each journal is ranked differently depending on the h-index, the number of citations and the articles for each journal. Specifically:

The Early Childhood Education Journal (ECEJ) ranked first with an h-index of six. This journal published its first article on this topic in 2013. And until July 2022, the journal published 11 articles on this topic with 213 citations (an average of 19.36 citations per article). The next group is four journals with the same h-index of four. The second-ranked in this top 12 is the International Journal of Technology and Design Education (IJTDE), which also started publishing on this topic in 2013 and has received more than 200 citations like ECEJ. Even though IJTDE only has an h-index of four, this journal has an average of 46.80 citations per article. Thus, there is a considerable chance for IJTDE to take over the first place from ECEJ shortly.

Having the same h-index of three, the Early Education and Development (EED), the Frontiers in Psychology (FiP), the Journal of Information Technology Education – Innovations in Practice (JITE), and the PLOS ONE ranked sixth, seventh, eighth, and ninth, respectively. Although these journals only have three - six articles on the topic of STEAM/STEM in ECE, their citations also range from 30 to 97 times. Significantly, the EED and the JITE also have average citation rates of more than 20, which are much further from the rest journals on the list.

Finally, there are three journals with an h-index of two. In particular, either Sustainability or the Journal of Early Childhood Research (JECR) has only four articles on STEAM/STEM in ECE. However, those two journals received 57 and 41 citations, with an average of 14.25 and 10.25 citations/articles. Education Sciences, despite owning 12 articles - the largest number of the top 12, has only 19 citations, which leads to the lowest average citation rate (1.58 per article). In general, the top impactful journals came from ECE and Educational technology categories, while the journals with broader scopes such as Education Sciences, PLOS ONE, and Sustainability did not have outstanding results within this ranking.

The researchers considered total citations the first filter to identify authors with the most influential research output. Then, the h-index is supposed to determine research quality and quantity stability in the respective citation group. In addition, besides the number of articles, the articles fractionalized indexes (AF) are used to assess each author's contribution to their collaborated works. Finally, we based on each author's first year of publication on this topic to calculate the average citation per article, which determines the average impact of each author over the years. As a result of these above processes, table 2 presents the top ten influencing authors.

Table 2. The Top 10 Most Prolific Authors in the Field of STEM Education in Early Childhood Education, Ranked by the Total Citation Count, H-Index and the Total Number of Publications

No	Authors	TC	H index	Articles	AF	PY Start	Citation/Year
1	BERS M.U.	489	9	10	5.17	2013	54.33
2	SULLIVAN A.	429	8	8	3.67	2013	47.67
3	KAZAKOFF E.R.	180	2	2	0.67	2013	20.00
4	PERREN S.	87	3	3	0.83	2007	5.80
4	STADELMANN S.	87	3	3	0.83	2007	5.80
4	VON KLITZING K.	87	3	3	0.83	2007	5.80
7	WARTELLA E.	73	2	3	0.75	2016	12.17
8	RAVID D.	72	2	2	0.83	2001	3.43
9	ALADE F.	70	1	2	0.50	2016	11.67
10	JUNG S.E.	63	2	3	1.00	2018	15.75

Started publishing about STEM/STEAM education in ECE in 2013; the two authors own the highest number of published articles, h-index and citations on WoS are Bers MU (ten articles, h-index of eight, 489 citations) and Sullivan A (eight articles, h-index of eight, 429 citations). In particular, Bers MU is the sole author of one paper (Bers, 2019) and collaborated with other researchers on nine works with an AF number of 5.17. Sullivan collaborated with Bers MU on all eight articles and has an AF of 3.67. Ranked third in the top ten most cited authors on this topic is Kazakoff ER, with 180 citations, two papers, and an AF of 0.67. He has participated in these articles with Bers MU and Sullivan A - the top two authors on this topic. The joint article of those three authors also received the highest citation rate is "The Effect of a Classroom-Based Intensive Robotics and Programming Workshop on Sequencing Ability in Early Childhood" (Kazakoff et al., 2013), with 136 citations.

Three authors, Perren S, Stadelmann S, and Von Klitzing K, ranked together in fourth place due to their collaboration on three articles with 87 citations, 5.8 citations/year. Notably, their most cited paper (Stadelmann et al., 2010) gained 33 citations. Finally, the remaining authors in this top 10 include Wartella E, Ravid D, Alade F and Jung SE, who has 63-73 citations, and about 12-15 citations per year. The differences between their h-index scores are insignificant, as they have less than three published works in this database.

Besides determining top journals and authors, this paper also captured the top 10 influencing papers studying STEM in ECE. Table 3 provides information about those articles, including the first author's name, journal, DOI, total citation, local citation, and average citations per year.

Table 3: Top 10 Impactful Research Articles about STEM in ECE From 1992 to 2022

No	Citations	Journal	DOI	TC	LC	AV
1	Ceci et al. (2014)	Psychological Science in the Public Interest	10.1177/1529100614541236	419	0	46.56
2	Brophy et al. (2008)	Journal of Engineering Education	10.1002/j.2168-9830.2008.tb00985.x	349	7	23.27
3	Ladd et al. (2000)	Merrill-Palmer Quarterly-Journal of Developmental Psychology		169	1	7.35
4	Kazakoff et al. (2013)	Early Childhood Education Journal	10.1007/s10643-012-0554-5	147	11	14.70
5	Sullivan & Bers (2016)	International Journal of Technology and Design Education	10.1007/s10798-015-9304-5	136	12	19.43
6	Darling-Hammond (1994)	Harvard Educational Review	10.17763/haer.64.1.j57n353226536276	96	0	3.31
7	Deflorio and Beliakoff (2015)	Early Education and Development	10.1080/10409289.2015.968239	75	2	9.38
8	Karoly & Gonzalez (2011)	Future of Children	10.1353/foc.2011.0005	72	0	6
9	Aladé et al. (2016)	Computers in Human Behavior	10.1016/j.chb.2016.03.080	75	5	10.71
10	Muenks et al. (2018)	Developmental Review	10.1016/j.dr.2018.04.001	69	0	13.80

Note: LC – local citation; AV - AV Citation Per Year, TC - Total Citations

Ranked in the first position is the work of (Ceci et al., 2014) entitled "Women in Academic Science: A Changing Landscape". Narrated the presence of women in undergraduate, graduate, and math-intensive fields, this paper received 419 citations, with an average of 46.56 per year after nine years (double the average citation of the 2nd paper). However, it has not received any citation from other research within this database.

Ranked in the second position, the article "Advancing Engineering Education in P-12 Classrooms" by Brophy et al. (2008) discusses how to integrate technology into the curriculum effectively (Brophy et al., 2008). This work got 349 citations and an average annual citation of 23.27 and got cited seven times by other papers from this dataset.

Of the remaining articles, there are three articles with more than 100 citations: (i) "Children's Initial Sentiments About Kindergarten: Is School Liking an Antecedent of Early Classroom Participation and Achievement?" by Ladd et al. (2000)(ii) The Effect of a Classroom-Based Intensive Robotics and Programming Workshop on Sequencing Ability in Early Childhood by (Kazakoff et al., 2013); and (iii) "Robotics in the early childhood classroom: learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade" by (Sullivan & Bers, 2016). The rest in the top 10 received around 70 citations. Significantly, all those ten papers did not receive adequate numbers of local citations compared to their total citations. Similar to the work of (Ceci et al., 2014), several articles by Ladd et al. (2000), Darling-Hammond (1994), Karoly and Gonzalez (2011), and Muenks et al. (2018) also acquired vast numbers of global citations but received only one or zero local citation (Darling-Hammond, 1994; Karoly & Gonzalez, 2011; Ladd et al., 2000; Muenks et al., 2018). The two articles with the most local citations are (Kazakoff et al., 2013) and (Sullivan & Bers, 2016), with 11 and 12 local citations, respectively, even though they were published in 2013 and 2016. These low results are understandable as this research topic is still new, and there are many gaps about Robotic that need to be addressed.

The Most Researched Keywords, Themes, and Topics in The Knowledge Base of STEM in ECE

Co-occurrence analysis is a method to figure out prominent publication topics in a particular research area by exploring the overlap and interconnections between keywords (Xing et al., 2018). Within this study, we consider keywords provided by both authors and journals. The researchers considered a threshold of eight, which means a keyword must appear at least eight times within this dataset and came up with a co-occurrence network that classified the 43 most common keywords into five clusters (Figure 5).

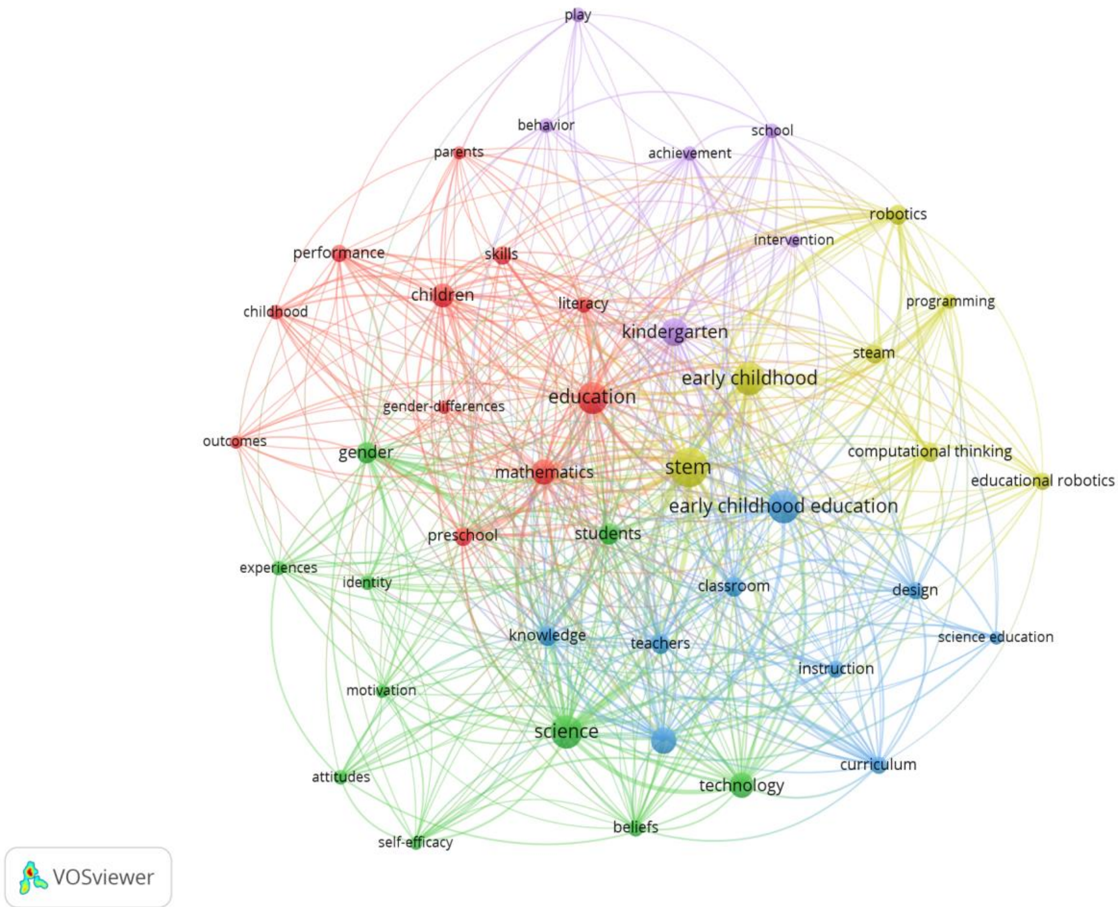

Figure 5. Co-occurrence Network of 43 Most Popular Keywords About STEM in ECE

The red cluster combines terms related to the child's outcome in the process of receiving STEM in preschool. The yellow cluster refers to computational thinking and educational robotics. The blue cluster focuses on dimensions related to teachers' STEM teaching. Two factors affecting teachers' STEM teaching have been researched a lot related to the two prominently displayed keywords of this cluster: "knowledge" and "curriculum". The green cluster is associated with gender equality in science and technology. The purple cluster with keywords: "achievement", "intervention"; "behavior"; "play"; "kindergarten", "school" refer to aspects of children's STEM achievement in preschool.

The number of times two objects (authors, documents, or journals) are cited in a third article is called co-citation. (Chen, 2006; Hjørland, 2013) stated that co-citation analysis is a technique for science mapping that assumes publications that are cited together frequently are similar thematically. By revealing the papers that co-cited each other, co-citation can identify the research focus on international Early STEM education (Hallinger & Kovačević, 2021). Among 308 documents examined by the VOSviewer, twenty-one documents with a minimum of ten citations are shown in Figure 6, divided into three clusters. These clusters exposed the different perspectives present in the literature, offering a broad view of the critical subjects (Gümüş et al., 2020). Therefore, the primary topics in the literature could be shown by examining each cluster's most substantial and unique documents (Cao et al., 2021).

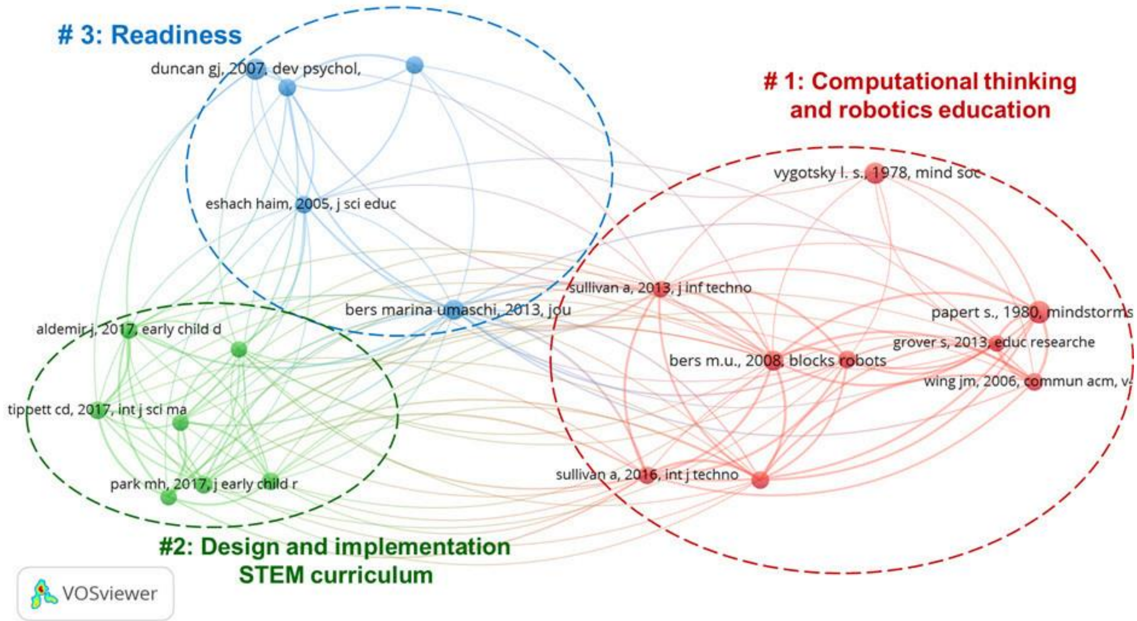

Figure 6. Science Mapping of 21 Documents with at least Ten Citations Based on Co-Citation Analysis

Documents in the red cluster focused on Computational thinking and robotics education. The most co-cited documents in this group are two documents named "Mindstorms: children, computers, and powerful ideas" (Papert, 1980) and "Mind in Society: Development of Higher Psychological Processes" (Vygotsky, 1978), which were published before 1992. These documents emphasized using objects as a tool to alter children's inner world and the world around them (Vygotsky, 1978) and how computers could prepare children to succeed in the ever-evolving tech world (Papert, 1980). Based on the theoretical foundations of these publications about children's developmental processes, other documents explored the impact of the implementation of a robotics curriculum on K-2 children's knowledge of foundational robotics and programming concepts (Sullivan & Bers, 2016) and their sequencing ability (Kazakoff et al., 2013). The majority of papers in this category affirmed that young children have the capacity to grasp multiple facets of robotics, programming, and computational thinking (Bers et al., 2014). The literature gaps were identified and prioritized for future inquiries were articulated (Grover & Pea, 2013). They also proposed implications for developmentally appropriate technology design, structure, and pace of robotics curriculum for young children.

The green cluster focused more directly on the Design and implementation STEM curriculum. The number of co-citations of documents in this cluster is not much different from each other, from 10 to 12 co-citations. The research on these topics argued the importance of the STEM/ STEM program (Sanders, 2009) and revealed that teachers' perceptions of their preparedness to teach STEM, their recognition of the significance of STEM education, and the obstacles they might face in STEM instruction (Park et al., 2017). Tippett and Milford (2017) investigated parents' opinions about STEM in general and STEM as experienced by their children. These investigations highlighted that parents regarded STEM as a vital component of their child's education and growth. Moreover, a significant portion of the research aimed to establish a comprehensive STEM education framework, curriculum, or model to enhance children's STEM skills and knowledge, while also enhancing preschool teachers' attitudes and their abilities to plan and incorporate STEM concepts into classroom activities (Aldemir & Kermani, 2017). Their findings suggested that child-centered learning, active involvement, varied resources, peer collaboration, and teacher guidance should be at the core of STEM curriculum activities. They also highlighted the insufficiency in the availability of resources, the need for enhancing teacher training in STEM fields, and the potential difficulties teachers might face when instructing STEM subjects.

The final cluster is in blue, which can be named readiness. Documents in this cluster researched the relationships between STEM subject achievement and children's readiness for school and the effects of professional development workshops on increasing teachers' knowledge and practice in robotics, engineering, and programming. The most cited documents in this group are documents of (Duncan et al., 2007) and (Bers et al., 2013). In their study, Duncan et al., (2007) investigated the connections among three fundamental components of school readiness: academic readiness at the start of school, attention skills, and socioemotional skills, in relation to subsequent academic achievements in reading and mathematics. Their research indicated that early mathematical abilities exhibit the highest predictive capability, followed by reading and attention skills (Duncan et al., 2007). Besides, some researchers concluded that children's readiness scores in science were significantly lower than those in all other measured domains. They also underscored the significance of prioritizing science within preschool environments, and the crucial role that science education can have in improving both early childhood classroom methodologies and student achievements (Eshach & Fried, 2005;

Greenfield et al., 2009; Radziwill et al., 2015). Furthermore, Bers et al. (2013) discovered a favorable impact of professional development workshops on enhancing teachers' comprehension of robotics, engineering, programming, and effective teaching methods for these subjects in early childhood settings. They also observed improvements in various aspects of technology self-confidence and attitudes toward technology.

Thematic Analyses:

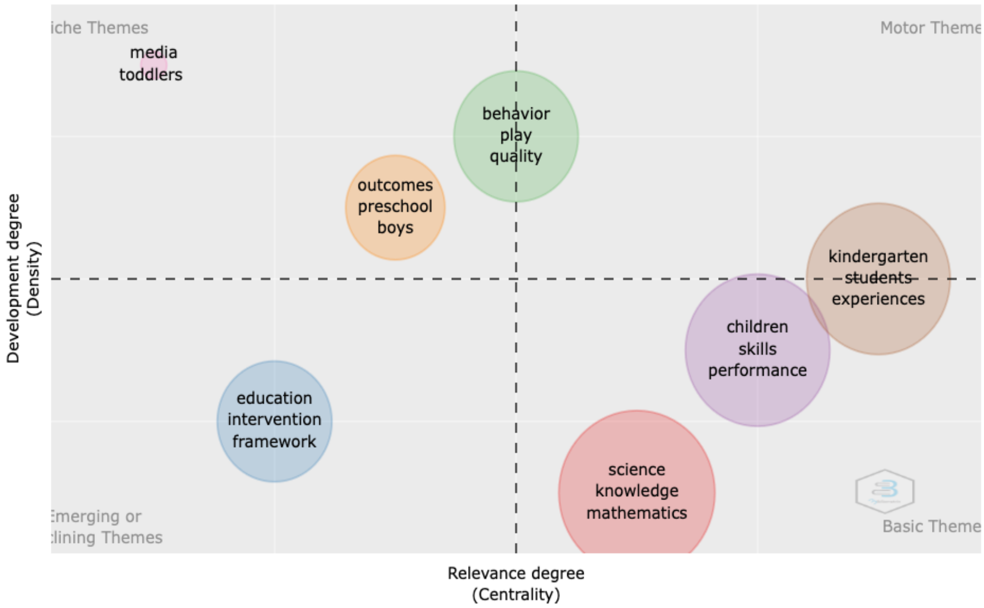

Figure 7. Thematic Analysis of Keywords Plus

Besides co-occurrence and co-citation analyses, the authors conducted thematic analyses to emphasize the development trend of research on STEM in ECE. Figure 7 describes the (i) basic themes, (ii) motor themes, (iii) niche themes, and (iv) emerging or declining themes of research about STEM in ECE from 1992 to 2022. First, we can realize "behavior", "play", and "quality" are keywords with the highest levels of density, which means researchers spend most of their attention on those areas. Second, the keywords that have connections with most of the studies on this dataset are in the quarter Basic theme: "Science", "knowledge", and "mathematics", which accounted for 8%, 3% and 3% of all studies, respectively. Besides, there are three different basic themes, such as "children", "skills", and "performance". Third, regarding the motor themes, which are both well developed and essential for the structure of the research field, "kindergarten" (5%), "behavior" (2%) and "play" (2%) are the most popular keywords. Fourth, besides the well-established niche research topics about preschoolers' "outcomes" and "gender", there is a new booming niche about "media". Finally, there is a lack of novel studies about "intervention" and "framework".

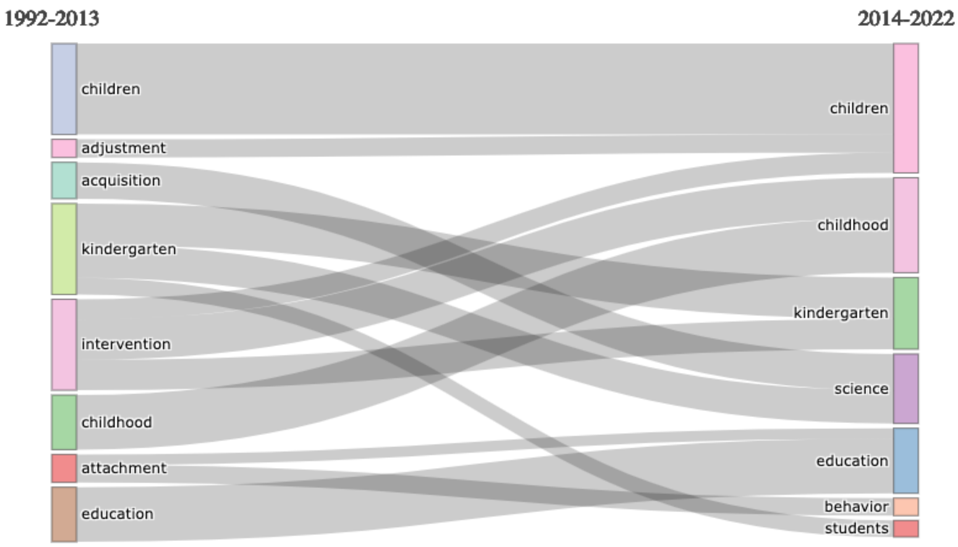

Figure 8. Sankey's Flow of Research Focuses on STEM in ECE From 1992 to 2022

We also performed a thematic revolution analysis to supplement the findings from density and centrality thematic analyses. The Sankey's flow (Figure 8) divides research focuses on STEM in ECE from 1992 to 2022 into two periods: 1992-2013 and 2014-2022, with "children" as the primary research objects across both periods. The popular topics in the period 1992-2013 were "children" (Costa-Giomi, 2003; Karoly & Gonzalez, 2011), "kindergarten" (Sullivan et al., 2013) and "education" (Brophy et al., 2008) . These topics continued to be studied more extensively at the later stage. Other primary focuses in the period 1992-2013, such as "acquisition", "intervention", and "attachment", became the foundation for studies on "science" and "behaviors" in later phases.

Discussion

Researchers' interest in STEM (science, technology, engineering, mathematics) has increased over the past decades; highlights the need to develop skills related to these principles (World Economic Forum, 2016), such as 'problem solving, critical thinking, inductive and deductive reasoning, goal setting goals, decision making' (Organisation for Economic Co-operation and Development, 2016, 2019). Similar to previous studies (Ha et al., 2020; Marín-Marín et al., 2021; Su & Yang, 2023), this study also shows an increase in the number of publications about STEM education in ECE (Radeva, 2020).

Our research found more documents than Su and Yang (2023) and also had different results. For example, this study shows that, in the list of countries with the highest number of publications on this topic, Turkey only ranks fourth instead of second as published by Su and Yang (2023). Furthermore, the research topics are also quite different, only overlapping in Robotics research. For the rest, we point out the topics of interest, different from Su and Yang (2023). The three main topics pointed out in this research are 'the child's outcome', 'computational thinking and educational robotics', and 'teacher STEM teaching'. At the same time, two less prominent topics are 'gender equality in science and technology', and 'children's STEM achievement' in preschool.

The researchers have demonstrated that studies focusing on STEM education are linked to enhancements in spatial aptitude among 5 to 6-year-old children, particularly those with mathematical abilities at an average level or below. Furthermore, STEM instruction predominantly influences children's mathematical skills through their block-building abilities (He et al., 2021). New literacy is understood as the way to read the codes of the 21st century. Children can code and run the robot during STEM activities with fun and excitement (González-González, 2019). In addition, parental "involvement" and "gender" also affect children's STEM competence. For instance, Salvatierra and Cabello (2022) confirmed that STEM education activities in preschool can promote parent involvement and that parents have a role in shaping children's interests in STEM. Also, girls have more difficulty accessing technical, science, and engineering activities in the classroom (Fleer, 2021; Ho et al., 2020; Stephenson et al., 2022).

Computational thinking is closely related to programming and various problem-solving skills. Robotics is an embedded approach in the STEM education curriculum in ECE (González-González, 2019). In the digital age, there are efforts to bring computational thinking into STEM education to train young citizens capable of facing complex problems in a modern context (Speldewinde, 2022). During early childhood time, children can master basic programming and robotics skills (Sullivan & Bers, 2016).

Research trends on knowledge associated with keywords such as "teacher", "knowledge", "science education", and "instruction". Research indicates that educators have some awareness of the STEM concept, yet their understanding is restricted when it comes to the integration procedures and the fundamental techniques and proficiencies needed to facilitate it (Alghamdi, 2023). Most teachers went to college and earned their degrees before STEM became the focus. Teachers consider that they need further training and professional development related to STEM implementation (Alghamdi, 2023). Mostly, research about STEM curriculum associated with keywords: "curriculum", "teacher", and "design". A study conducted in China on the views and views of Chinese educators about early technology education found that teachers are virtually illiterate in terms of ICT and the curriculum. Technology and digital technology need to be carefully designed to meet the needs of young children (Weng & Li, 2020). Programs are experimentally intended to improve the effectiveness of STEM teaching (Fuller et al., 2021). Most preschool and preschool curricula are challenging and engaging, with only a few having a solid foundation in STEM (Tay et al., 2018)

In many fields of Science, Technology, Engineering and Mathematics, especially engineering and computer science fields, there are more men than women. A developmentally appropriate robotics curriculum can increase girls' interest in engineering (Sullivan & Bers, 2019). New spaces have been created to remove the barriers and challenges of traditional STEM spaces for girls, enabling them to participate in STEM activities (Fleer, 2021; Stephenson et al., 2022). So, the primary concern is whether girls can participate equally in STEM educational activities in preschool. At the same time, STEM fields are priority areas for improving children's achievement in kindergarten. Effective interventions can improve the achievement of preschoolers in science subjects as well as reduce achievement gaps between children of different preschool models, children of different races, and children with different income parents (Curran, 2019).

Furthermore, by observation of Figure 6, we can pinpoint the papers that exhibit notable influences and associations with various lines of thinking prevalent in the literature. In particular, the authors or documents frequently positioned at the focal point of the co-citation map are consistently seen as pivotal components bridging various perspectives, playing a critical role in advancing the literature by elevating their impact and reducing the scholarly distance between papers emanating from distinct schools of thought (Cao et al., 2021; Udomsap & Hallinger, 2020; White & McCain, 1998). Although Duncan et al. (2007); Papert (1980) and Vygotsky (1978) are the three most co-cited documents, with a total link strength of 32, 13, and 8, respectively, Sullivan and Bers (2016) has the highest total link strength, with 44, which is greater than the other papers in the top five co-citations. This is an intriguing case of documents with a powerful connection but having minor impacts.

Based on the information in Figure 8, It can be assumed that: (a) There is a crossroads between studies on acquisition, kindergarten, intervention, and childhood, and (b) Attachment theories delved into the study of behavior. For instance, Brophy et al. (2008) did research on "Advancing engineering education in P-12 classrooms", which was followed by the article "STEM in the early years" by Katz (2010). Based on these two studies, Tippett and Milford (2017) contributed the article "Findings from a Pre-kindergarten Classroom: Making a case for STEM in Early Childhood Education" (Tippett & Milford, 2017). Overall, from 2014 onwards, "science" became one of the new research focuses in ECE, based on the prior foundations of research about "acquisition".

Conclusions

This study explored the development of publications on STEM education in ECE by utilizing bibliographic data from the WoS databases over the 1992 - 2022 period, including 308 publications. The main findings of this study are:

Firstly, although research on STEM education in ECE has been carried out since 1992 and has consistently increased, the quantity of research on this subject has experienced a substantial surge since 2016. Along with the increased published research, citations have also increased significantly during this time. In addition, while the US has the most studies and the most extensive influence on other research on STEM in ECE, China and Israel are the two countries that account for the majority of publications in Asia. Furthermore, academic circles have developed, and core researchers collaborate closely, which is essential for increasing its influence. The United States, China, and Germany engage in the most robust international collaborative research with other countries.

Secondly, the most successful and influential journals and authors are also highlighted in this study. Specifically, while two journals named "Early Childhood Education Journal" and "International Journal of Technology and Design Education" have the most significant influences, Bers MU and Sullivan A are two scholars with the most significant impact in the research field. The publications from these journals and authors have established a foundation for subsequent studies.

Thirdly, keyword co-occurrence showed that various keywords had been used in the research over the three decades. The research themes of STEM in ECE are very varied such as the outcome of children in process STEM activities, mathematical competence, parental involvement, and new literacy; research on computational thinking and educational robotics, research on STEM teaching process of preschool teachers, and research on gender equality in STEM education activities for preschoolers. Co-citation analysis displayed that the most cited documents that focus on three significant schools of thought, such as the accessibility to technology, benefits and impacts of technology on children's acquisition of knowledge and skills; directions for implementing STEM/STEAM education curriculum; teachers' attitudes to implementing STEM curriculum; parental involvement; the difficulties in facilities and teachers' knowledge and skills. Researchers also examined the correlations between students' performance in STEM subjects and their preparation for school and the impact of professional development workshops on teachers' understanding of and use of robotics, engineering, and programming.

Finally, the thematic analysis showed the transformation of research themes and trends on STEM in ECE. A variety of hot research topics from 1992-2013 were combined in the 2014 - 2022 period, which made crossroads between studies on acquisition, kindergarten, intervention, and childhood. Furthermore, incorporating the themes of child behaviour and attachment in STEM learning and science learning in preschool is also a concern of the late period.

Recommendations

While robust enthusiasm towards STEM/STEAM is observable across numerous nations, the imperative for heightened scholarly investigation and practical integration within developing nations becomes evident. Furthermore, reinforcing transnational collaborative research endeavours is necessary, leveraging pre-established research affiliations concerning this domain between developed and developing nations. STEM education is agreed upon as an educational approach suitable for the future, aimed at achieving general educational goals, including sustainable development goals (Zhan et al., 2022). Therefore, this topic needs to be researched in preschools as a preparation for formal education in high schools. Countries in the Asian region, other than China, seem to be slower than countries in Europe, America, and Australia in researching STEM in ECE. Although, for example, in the Southeast Asia region, STEM education has been researched quite strongly (Ha et al., 2020), there seems to be a lack in ECE. Apparently, similar to the study Ha et al. (2020), countries with a slower start can find opportunities to cooperate in research with more experienced countries that are ahead in research on this topic. Similar to publications on STEM education in general (Zhan et al., 2022), the United States is also the leading country in publications on STEM in ECE.

As a result of this study, emerging researchers and policymakers can explore documents and seek guidance from the most influential academics, enabling them to establish pertinent research directions and make informed policy decisions. Furthermore, the study's identification of the most influential scientific journals will serve as valuable references for young researchers, providing access to the latest and high-quality publications in the field of STEM education in ECE.

In general, research topics related to STEM education in ECE are quite diverse and there are not too many publications. Therefore, the opportunity for researchers to make academic contributions is quite large, especially for researchers in developing countries. For example, differences in culture and physical conditions in schools will also create differences in the design and application of STEM education in ECE as well as its effectiveness.

Limitations

Although the findings of this study would contribute to furthering research in the field of STEM in ECE, it has certain limitations in any case. Firstly, this study only included English-language papers in WoS while gathering data. Other databases, such as Scopus and PubMed, also need consideration. Additionally, aside from the United States and Australia, Spain, Turkey, and Greece, where English is not the predominant first language, also make substantial contributions to the publication count. Examining articles written in languages other than English may provide an alternate perspective and a more profound understanding of the local context.

Secondly, the primary focus of the bibliometric analysis techniques utilized in this study is a quantitative and descriptive overview of the literature. Therefore, it only acts as a starting point for new research on STEM in ECE. Unlike standard meta-analyses, we cannot address issues with the literature, such as effect sizes and publication bias. Furthermore, bibliometric analysis could not allow us to analyze the details of the STEM in ECE topic and assess the quality of each piece of research. Therefore, further studies, combining this analysis method with other analytical methods, such as systemetic analysis, are needed to overcome this limitation.

Thirdly, the analysis involved the utilization of two widely used and efficient bibliographic analysis tools, namely, Biblioshiny and VOSviewer. However, it's worth noting that certain functional limitations currently exist, such as the inability to provide statistics on scholars by gender or statistics on emerging scholars by year.

Ultimately, as previously indicated, bibliometric analysis falls short of achieving a comprehensive conceptualization of STEM in ECE. Given that the primary objective of this approach lies in presenting a holistic overview of the investigative subject, meticulous scrutiny of the substance of the research is not encompassed. Similarly, the revelations drawn from the author's analysis of keywords may prove deficient, as they might not adequately encapsulate the essence of the designated articles. Nevertheless, this investigation holds the potential to constitute a meaningful initiatory point for scholars who harbour an inclination towards interconnected subject matters.

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Conflict of Interest

The authors declare that they have no conflict of interest in this research.

Authorship Contribution Statement

T.-L. Bui and M.-T. Nguyen: Conceptualize, supervision. T.-T. Tran: Data curation, writing – original draft. T.-H. Nguyen, and T.-L. Nguyen: Data curation, writing – original draft. C.-T. Vu, V.-N. Tran and U.-P. Dang: Methodology, writing – review & editing. A.-D. Hoang: Methodology, writing – review & editing, supervision.

References

Akcay Malcok, B., & Ceylan, R. (2022). The effects of STEM activities on the problem-solving skills of 6-year-old preschool children. *European Early Childhood Education Research Journal, 30*(3), 423-436. https://doi.org/10.1080/1350293x.2021.1965639

Aladé, F., Lauricella, A. R., Beaudoin-Ryan, L., & Wartella, E. (2016). Measuring with Murray: Touchscreen technology and preschoolers' STEM learning. *Computers in Human Behavior*, *62*, 433-441. https://doi.org/10.1016/j.chb.2016.03.080

Aldemir, J., & Kermani, H. (2017). Integrated STEM curriculum: Improving educational outcomes for head start children. *Early Child Development and Care*, *187*(11), 1694-1706. https://doi.org/10.1080/03004430.2016.1185102

Alghamdi, A. A. (2023). Exploring early childhood teachers' beliefs about STEAM education in Saudi Arabia. *Early Childhood Education Journal*, *51*, 247-256. https://doi.org/10.1007/s10643-021-01303-0

Ata Aktürk, A., & Demircan, H. O. (2017). A review of studies on STEM and STEAM education in early childhood. *Ahi Evran Üniversitesi Kırşehir Eğitim Fakültesi Dergisi*, *18*(2), 757-776. https://s.net.vn/CRa7

Bers, M. U. (2019). Coding as another language: A pedagogical approach for teaching computer science in early childhood. *Journal of Computers in Education*, *6*, 499-528. https://doi.org/10.1007/s40692-019-00147-3

Bers, M. U. (2020). *Coding as a playground: Programming and computational thinking in the early childhood classroom*. Routledge. https://doi.org/10.4324/9781003022602

Bers, M. U., Seddighin, S., & Sullivan, A. (2013). Ready for robotics: Bringing together the T and E of STEM in early childhood teacher education. *Journal of Technology and Teacher Education*, *21*(3), 355-377. https://bit.ly/3wtNiT4

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: exploration of an early childhood robotics curriculum. *Computers and Education*, *72*, 145-157. https://doi.org/10.1016/j.compedu.2013.10.020

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, *97*(3), 369-387. https://doi.org/10.1002/j.2168-9830.2008.tb00985.x

Bukar, U. A., Sayeed, M. S., Razak, S. F. A., Yogarayan, S., Amodu, O. A., & Mahmood, R. A. R. (2023). A method for analyzing text using VOSviewer. *MethodsX, 11*, Article 102339. https://doi.org/10.1016/j.mex.2023.102339

Bybee, R. W., & Fuchs, B. (2006). Preparing the 21st century workforce: A new reform in science and technology education. *Journal of Research in Science Teaching, 43*(4), 349-352. https://doi.org/10.1002/tea.20147

Cao, Q. -T., Vuong, Q. -H., Pham, H. -H., Luong, D. -H., Ho, M. -T., Hoang, A. -D., & Do, M. -T. (2021). A Bibliometric review of research on international students' mental health: Science mapping of the literature from 1957 to 2020. *European Journal of Investigation in Health, Psychology and Education*, *11*(3), 781-794. https://doi.org/10.3390/ejihpe11030056

Ceci, S. J., Ginther, D. K., Kahn, S., & Williams, W. M. (2014). Women in academic science. *Psychological Science in the Public Interest*, *15*(3), 75-141. https://doi.org/10.1177/1529100614541236

Chen, C. (2006). CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for Information Science and Technology*, *57*(3), 359-377. https://doi.org/10.1002/asi.20317

Chiu, W. -T., & Ho, Y. -S. (2007). Bibliometric analysis of tsunami research. *Scientometrics, 73*, 3-17. https://doi.org/10.1007/s11192-005-1523-1

Costa-Giomi, E. (2003). Young children's harmonic perception. *Annals of the New York Academy of Sciences*, *999*(1), 477-484. https://doi.org/10.1196/annals.1284.058

Curran, F. C. (2019). Estimating the relationship between preschool attendance and kindergarten science achievement: Implications for early science achievement gaps. *Education Finance and Policy*, *14*(2), 210-241. https://doi.org/10.1162/edfp_a_00247

Darling-Hammond, L. (1994). Performance-based assessment and educational equity. *Harvard Educational Review*, *64*(1), 5-31. https://doi.org/10.17763/haer.64.1.j57n353226536276

DeFlorio, L., & Beliakoff, A. (2015). Socioeconomic status and preschoolers' mathematical knowledge: The contribution of home activities and parent beliefs. *Early Education and Development*, *26*(3), 319-341. https://doi.org/10.1080/10409289.2015.968239

DeJarnette, N. K. (2018). Implementing STEAM in the early childhood classroom. *European Journal of STEM Education*, *3*(3), Article 18. https://doi.org/10.20897/ejsteme/3878

Do, T. -T., Tinh, P. T., Tran-Thi, H.-G., Bui, D. M., Pham, T. O., Nguyen-Le, V.-A., & Nguyen, T.-T. (2021). Research on lifelong learning in Southeast Asia: A bibliometrics review between 1972 and 2019. *Cogent Education, 8*(1), Article 1994361. https://doi.org/10.1080/2331186X.2021.1994361

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology*, *43*(6), 1428-1446. https://doi.org/10.1037/0012-1649.43.6.1428

Eshach, H., & Fried, M. N. (2005). Should science be taught in early childhood? *Journal of Science Education and Technology*, *14*, 315-336. https://doi.org/10.1007/s10956-005-7198-9

Fleer, M. (2021). Re-Imagining play spaces in early childhood education: Supporting girls' motive orientation to STEM in times of COVID-19. *Journal of Early Childhood Research*, *19*(1), 3-20. https://doi.org/10.1177/1476718X20969848

Fuller, J. A., Luckey, S., Odean, R., & Lang, S. N. (2021). Creating a diverse, inclusive, and equitable learning environment to support children of color's early introductions to STEM. *Translational Issues in Psychological Science*, *7*(4), 473-486. https://doi.org/10.1037/tps0000313

Geary, D. C., Hoard, M. K., Nugent, L., & Bailey, D. H. (2013). Adolescents' functional numeracy is predicted by their school entry number system knowledge. *PLoS ONE, 8*(1), Article e54651. https://doi.org/10.1371/journal.pone.0054651

Gil-Doménech, D., Berbegal-Mirabent, J., & Merigó, J. M. (2020). STEM education: A bibliometric overview. In J. Ferrer-Comalat, S. Linares-Mustarós, J. Merigó, & J. Kacprzyk (Eds.), *Modelling and Simulation in Management Sciences: Proceedings of the International Conference on Modelling and Simulation in Management Sciences (MS-18)* (pp. 193-205). Springer. https://doi.org/10.1007/978-3-030-15413-4_15

González-González, C. S. (2019). State of the art in the teaching of computational thinking and programming in childhood education. *Education in the Knowledge Society (EKS)*, *20*, Article 15. https://doi.org/10.14201/eks2019_20_a17

Greenfield, D. B., Jirout, J., Dominguez, X., Greenberg, A., Maier, M., & Fuccillo, J. (2009). Science in the preschool classroom: A programmatic research agenda to improve science readiness. *Early Education and Development*, *20*(2), 238-264. https://doi.org/10.1080/10409280802595441

Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. *Educational Researcher*, *42*(1), 38-43. https://doi.org/10.3102/0013189X12463051

Gümüş, S., Bellibaş, M. Ş., Gümüş, E., & Hallinger, P. (2020). Science mapping research on educational leadership and management in Turkey: A bibliometric review of international publications. *School Leadership and Management*, *40*(1), 23–44. https://doi.org/10.1080/13632434.2019.1578737

Ha, C. T., Thao, T. T. P., Trung, N. T., Huong, L. T. T., Dinh, N. V., & Trung, T. (2020). A Bibliometric review of research on STEM education in ASEAN: Science mapping the literature in Scopus database, 2000 to 2019. *Eurasia Journal of Mathematics, Science and Technology Education, 16*(10), Article em1889. https://doi.org/10.29333/ejmste/8500

Hallinger, P., & Kovačević, J. (2021). Science mapping the knowledge base in educational leadership and management: A longitudinal bibliometric analysis, 1960 to 2018. *Educational Management Administration and Leadership*, *49*(1), 5-30. https://doi.org/10.1177/1741143219859002

He, X., Li, T., Turel, O., Kuang, Y., Zhao, H., & He, Q. (2021). The impact of STEM education on mathematical development in children aged 5-6 years. *International Journal of Educational Research*, *109*, Article 101795. https://doi.org/10.1016/j.ijer.2021.101795

Helm, J. H., & Katz, L. G. (2016). *Young investigators: The project approach in the early years*. Teachers College Press.

Hjørland, B. (2013). Facet analysis: The logical approach to knowledge organization. *Information Processing and Management*, *49*(2), 545-557. https://doi.org/10.1016/j.ipm.2012.10.001

Ho, M. -T., La, V. -P., Nguyen, M. -H., Pham, T. -H., Vuong, T. -T., Vuong, H. -M., Pham, H. -H., Hoang, A. -D., & Vuong, Q. -H. (2020). An analytical view on STEM education and outcomes: Examples of the social gap and gender disparity in Vietnam. *Children and Youth Services Review*, *119*, Article 105650. https://doi.org/10.1016/j.childyouth.2020.105650

Jamali, S. M., Ale Ebrahim, N., & Jamali, F. (2022). The role of STEM Education in improving the quality of education: A bibliometric study. *International Journal of Technology and Design Education*, *33*, 819-840. https://doi.org/10.1007/s10798-022-09762-1

Jamil, F. M., Linder, S. M., & Stegelin, D. A. (2018). Early childhood teacher beliefs about STEAM education after a professional development conference. *Early Childhood Education Journal*, *46*, 409-417. https://doi.org/10.1007/s10643-017-0875-5

Kang, N. -H. (2019). A Review of the effect of integrated STEM or STEAM (Science, Technology, Engineering, Arts, and Mathematics) education in South Korea. *Asia-Pacific Science Education, 5*, Article 6. https://doi.org/10.1186/s41029-019-0034-y

Karoly, L. A., & Gonzalez, G. C. (2011). Early care and education for children in immigrant families. *The Future of Children*, *21*(1), 71-101. https://doi.org/10.1353/foc.2011.0005

Katz, L. G. (2010). STEM in the early years. *Early Childhood Research and Practice, 12*(2), 11-19. https://s.net.vn/k5Ko

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal*, *41*~~(4)~~, 245-255. https://doi.org/10.1007/s10643-012-0554-5

Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers and Education*, *91*, 14-31. https://doi.org/10.1016/j.compedu.2015.08.005

Ladd, G. W., Buhs, E. S., & Seid, M. (2000). Children's initial sentiments about kindergarten: is school liking an antecedent of early classroom participation and achievement? *Merrill-Palmer Quarterly*, *46*(2), 255-279. https://www.jstor.org/stable/23093716

Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O. S., Hubert, T., & Almughyirah, S. (2016). Using robotics and game design to enhance children's self-efficacy, STEM attitudes, and computational thinking skills. *Journal of Science Education and Technology, 25*, 860-876. https://doi.org/10.1007/s10956-016-9628-2

Le Thi Thu, H., Tran, T., Trinh Thi Phuong, T., Le Thi Tuyet, T., Le Huy, H., & Vu Thi, T. (2021). Two decades of STEM education research in middle school: A bibliometrics analysis in Scopus database (2000–2020). *Education Sciences*, *11*(7), Article 353. https://doi.org/10.3390/educsci11070353

Lindeman, K. W., Jabot, M., & Berkley, M. T. (2014). The role of STEM (or STEAM) in the early childhood setting. In L. E. Cohen & S. Stupiansky (Eds.), *Learning across the early childhood curriculum* (Vol. 17, pp. 95-114). Emerald Group Publishing Limited. https://doi.org/10.1108/s0270-4021(2013)0000017009

Maeda, J. (2013). STEM + Art = STEAM. *STEAM*, *1*(1), Article 34. https://doi.org/10.5642/steam.201301.34

Makkizadeh, F., & Sa'adat, F. (2017). Bibliometric and thematic analysis of articles in the field of infertility (2011-2015). *International Journal of Reproductive BioMedicine, 15*(11), 719-728.

Maphosa, M., Doorsamy, W., & Paul, B. S. (2022). Factors influencing students' choice of and success in stem: a bibliometric analysis and topic modeling approach. *IEEE Transactions on Education*, *65*(4), 657-669. https://doi.org/10.1109/te.2022.3160935

Marín-Marín, J. -A., Moreno-Guerrero, A. -J., Dúo-Terrón, P., & López-Belmonte, J. (2021). STEAM in education: A bibliometric analysis of performance and co-words in Web of Science. *International Journal of STEM Education*, *8*, Article 41. https://doi.org/10.1186/s40594-021-00296-x

McClure, E. R., Guernsey, L., Clements, D. H., Bales, S. N., Nichols, J., Kendall-Taylor, N., & Levine, M. H. (2017). *STEM starts early: Grounding science, technology, engineering, and math education in early childhood*. The Joan Ganz Cooney Center at Sesame Workshop. https://bit.ly/3UN7Y2I

Mengmeng, Z., Xiantong, Y., & Xinghua, W. (2019). Construction of STEAM curriculum model and case design in kindergarten. *American Journal of Educational Research*, *7*(7), 485-490. https://doi.org/10.12691/education-7-7-8

Moore, T. J., & Smith, K. A. (2014). Advancing the state of the art of STEM integration. *Journal of STEM Education: Innovations and Research*, *15*(1), 5-10. https://shorturl.at/cqTY0 https://smith.cege.umn.edu/sites/smith.cege.umn.edu/files/2020-10/Moore-Smith-JSTEMEd-GuestEditorialF.pdf

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7), Article e1000097. https://doi.org/10.1371/journal.pmed.1000097

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 35-60). Purdue University Press. https://doi.org/10.2307/j.ctt6wq7bh.7

Morrin, A. M., & Liston, M. (2020). Engaging children with authentic STEAM learning experiences through design-based approaches. *Connected Science Learning,* *2*(4), Article 12318723. https://doi.org/10.1080/24758779.2020.12318723

Muenks, K., Wigfield, A., & Eccles, J. S. (2018). I can do this! The development and calibration of children's expectations for success and competence beliefs. *Developmental Review*, *48*, 24-39. https://doi.org/10.1016/j.dr.2018.04.001

Ng, A., Kewalramani, S., & Kidman, G. (2022). Integrating and navigating STEAM (InSTEAM) in early childhood education: An integrative review and insteam conceptual framework. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(7), Article em2133. https://doi.org/10.29333/ejmste/12174

Nguyen, T. -T., Pham, H. -H., Nguyen-Le, V. A., Nguyen, C. H., & Tran, T. (2023). Review of research on predatory scientific publications from Scopus database between 2012 and 2022. *Journal of Scholarly Publishing, 54*(2), 175-219. https://doi.org/10.3138/jsp-2022-0045

Organisation for Economic Co-operation and Development. (2016). *PISA 2015 assessment and analytical framework: Science, reading, mathematic and financial literacy*. OECD iLibrary. https://doi.org/10.1787/9789264255425-en

Organisation for Economic Co-operation and Development. (2019). *OECD future of education and skills 2030: OECD learning compass 2030. A series of concept notes.* https://s.net.vn/ZqAi

Özkaya, A. (2019). STEM eğitimi alanında yapılan yayınların bibliyometrik analizi [Bibliometric analysis of the publications made in STEM education area]. *Bartın University Journal of Faculty of Education/ Bartin Üniversitesi Egitim Fakültesi Dergisi*, *8*(2), 590-628. https://doi.org/10.14686/buefad.450825

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic.

Park, M. -H., Dimitrov, D. M., Patterson, L. G., & Park, D. -Y. (2017). Early childhood teachers' beliefs about readiness for teaching science, technology, engineering, and mathematics. *Journal of Early Childhood Research*, *15*(3), 275-291. https://doi.org/10.1177/1476718X15614040

Peng, D. (2020). Micro-project design of STEAM education for preschoolers based on striking life phenomena. *Education Journal*, *9*(3), 59-63. https://doi.org/10.11648/j.edu.20200903.11

Pham, H. -H., Dong, T. -K. -T., Vuong, Q. -H., Luong, D. -H., Nguyen, T. -T., Dinh, V. -H., & Ho, M. -T. (2021). A bibliometric review of research on international student mobilities in Asia with Scopus dataset between 1984 and 2019. *Scientometrics, 126*, 5201–5224. https://doi.org/10.1007/s11192-021-03965-4

Pham, P. -T., Lien, D. T. H., Kien, H. C., Chi, N. H., Tinh, P. T., Do, T., Nguyen, L. C., & Nguyen, T. -T. (2022). Learning management system in developing countries: A bibliometric analysis between 2005 and 2020. *European Journal of Educational Research, 11*(3), 1363-1377. https://doi.org/10.12973/eu-jer.11.3.1363

Pham-Duc, B., Tran, T., Trinh, T. -P. -T., Nguyen, T. -T., Nguyen, N. -T., & Le, H. -T. -T. (2022). A spike in the scientific output on social sciences in Vietnam for recent three years: Evidence from bibliometric analysis in Scopus database (2000–2019). *Journal of Information Science, 48*(5), 623-639. https://doi.org/10.1177/0165551520977447

Phan, T. T., Do, T. T., Trinh, T. H., Tran, T., Duong, H. T., Trinh, T. P. T., Do, B. C., & Nguyen, T. -T. (2022). A bibliometric review on realistic mathematics education in Scopus database between 1972-2019. *European Journal of Educational Research, 11*(2), 1133-1149. https://doi.org/10.12973/eu-jer.11.2.1133

Radeva, S. (2020). STEM education should support and encourage 21st century skills of children and sustainability and United National goals. In Ş. Ünlü Çetin, K. Bilican & M. Üçgül (Eds.), *Key points for STEM in early childhood education an involving parents: A guidebook for early childhood educators* (pp.4-9). Boyut Tanıtım Matbaa. https://bit.ly/470HBbM

Radziwill, N. M., Benton, M. C., & Moellers, C. (2015). From STEM to STEAM: Reframing what it means to learn. *Steam*, *2*(1), Article 3. https://doi.org/10.5642/steam.20150201.3

Robelen, E. W. (2011). Building STEAM: Blending the arts with STEM subjects. *Education Week*, *31*(13), 8-9.

Salvatierra, L., & Cabello, V. M. (2022). Starting at home: What does the literature indicate about parental involvement in early childhood STEM education? *Education Sciences*, *12*(3), Article 218. https://doi.org/10.3390/educsci12030218

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*, *68*(4), 20-27. https://bit.ly/3IaTPEN

Sharapan, H. (2012). From STEM to STEAM how early childhood educators can apply Fred Rogers' approach. *Young Children*, *67*(1), 36-40.

Sırakaya, M., & Alsancak Sırakaya, D. (2022). Augmented reality in STEM education: A Systematic review. *Interactive Learning Environments*, *30*(8), 1556-1569. https://doi.org/10.1080/10494820.2020.1722713

Simoncini, K., & Lasen, M. (2018). Ideas about STEM among Australian early childhood professionals: How important is STEM in early childhood education? *International Journal of Early Childhood*, *50*, 353-369. https://doi.org/10.1007/s13158-018-0229-5

Speldewinde, C. (2022). Where to stand? Researcher involvement in early education outdoor settings. *Educational Research*, *64*(2), 208–223. https://doi.org/10.1080/00131881.2022.2064323

Stadelmann, S., Perren, S., Groeben, M., & Von Klitzing, K. (2010). Parental separation and children's behavioral/emotional problems: The impact of parental representations and family conflict. *Family Process*, *49*(1), 92-108. https://doi.org/10.1111/j.1545-5300.2010.01310.x

Stephenson, T., Fleer, M., & Fragkiadaki, G. (2022). Increasing girls' STEM engagement in early childhood: Conditions created by the conceptual PlayWorld model. *Research in Science Education*, *52*, 1243-1260. https://doi.org/10.1007/s11165-021-10003-z

Su, J., & Yang, W. (2023). STEM in early childhood education: A bibliometric analysis. *Research in Science and Technological Education*. Advance online publication. https://doi.org/10.1080/02635143.2023.2201673

Sullivan, A., & Bers, M. U. (2016). Robotics in the early childhood classroom: Learning outcomes from an 8-Week Robotics Curriculum in Pre-Kindergarten Through Second Grade. *International Journal of Technology and Design Education*, *26*, 3-20. https://doi.org/10.1007/s10798-015-9304-5

Sullivan, A., & Bers, M. U. (2019). Investigating the use of robotics to increase girls' interest in engineering during early elementary school. *International Journal of Technology and Design Education*, *29*, 1033-1051. https://doi.org/10.1007/s10798-018-9483-y

Sullivan, A., Kazakoff, E. R., & Umashi Bers, M. (2013). The wheels on the bot go round and round: Robotics curriculum in pre-kindergarten. *Journal of Information Technology Education: Innovations in Practice*, *12*, 203-219. https://doi.org/10.28945/1887

Tao, Y. (2019). Kindergarten Teachers' attitudes toward and confidence for integrated STEM education. *Journal for STEM Education Research, 2*, 154-171. https://doi.org/10.1007/s41979-019-00017-8

Tay, J., Salazar, A., & Lee, H. (2018). Parental perceptions of STEM enrichment for young children. *Journal for the Education of the Gifted*, *41*(1), 5-23. https://doi.org/10.1177/0162353217745159

Tippett, C. D., & Milford, T. M. (2017). Findings from a pre-kindergarten classroom: Making the case for STEM in early childhood education. *International Journal of Science and Mathematics Education*, *15*, 67-86. https://doi.org/10.1007/s10763-017-9812-8

Trinh, T.-P.-T., Tran, T., Le, H.-T.-T., Nguyen, T.-T., Pham, H.-H. (2020). Factors impacting international-indexed publishing among Vietnamese educational researchers. *Learned Publishing,* *33*(4), 419-429. https://doi.org/10.1002/leap.1323

Udomsap, A. D., & Hallinger, P. (2020). A Bibliometric Review of research on sustainable construction, 1994–2018. *Journal of Cleaner Production*, *254*, Article 120073. https://doi.org/10.1016/j.jclepro.2020.120073

Van Eck, N. J., & Waltman, L. (2007). VOS: A new method for visualizing similarities between objects. In R. Decker, & H.-J. Lenz (Eds.), *Advances in data analysis: Studies in classification, data analysis, and knowledge organization* (pp. 299-306). Springer. https://doi.org/10.1007/978-3-540-70981-7_34

Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*, 523-538. https://doi.org/10.1007/s11192-009-0146-3

Van Eck, N. J., & Waltman, L. (2018). *VOSviewer Manual* (Version 1.6.8). VOSviewer. https://s.net.vn/sgai

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press. http://www.jstor.org/stable/j.ctvjf9vz4

Wahyuningsih, S., Nurjanah, N. E., Rasmani, U. E. E., Hafidah, R., Pudyaningtyas, A. R., & Syamsuddin, M. M. (2020). STEAM learning in early childhood education: A literature review. *International Journal of Pedagogy and Teacher Education*, *4*(1), 33-44. https://doi.org/10.20961/ijpte.v4i1.39855

Wan, Z. H., Jiang, Y., & Zhan, Y. (2021). STEM education in early childhood: A Review of empirical studies. *Early Education and Development, 32*(7), 940-962. https://doi.org/10.1080/10409289.2020.1814986

Weng, J., & Li, H. (2020). Early Technology education in China: A case study of Shanghai. *Early Child Development and Care*, *190*(10), 1574-1585. https://doi.org/10.1080/03004430.2018.1542383

White, H. D., & McCain, K. W. (1998). Visualizing a discipline: An author co-citation analysis of information science, 1972–1995. *Journal of the American Society for Information Science*, *49*(4), 327-355. https://doi.org/b57vc7

World Economic Forum. (2016, January 16). *The fourth industrial revolution: What it means, how to respond.* https://bit.ly/3ULgLlE

Xing, D., Zhao, Y., Dong, S., & Lin, J. (2018). Global research trends in STEM cells for osteoarthritis: A bibliometric and visualized study. *International Journal of Rheumatic Diseases*, *21*(7), 1372-1384. https://doi.org/10.1111/1756-185X.13327

Yu, Y. -C., Chang, S. -H., & Yu, L. -C. (2016). An academic trend in STEM education from bibliometric and cocitation method. *International Journal of Information and Education Technology*, *6*(2), 113-116. https://doi.org/10.7763/ijiet.2016.v6.668

Zeidler, D. L. (2016). STEM education: A deficit framework for the twenty first century? A sociocultural socioscientific response. *Cultural Studies of Science Education, 11*, 11-26. https://doi.org/10.1007/s11422-014-9578-z

Zhan, Z., Shen, W., Xu, Z., Niu, S., & You, G. (2022). A bibliometric analysis of the global landscape on STEM education (2004-2021): Towards global distribution, subject integration, and research trends. *Asia Pacific Journal of Innovation and Entrepreneurship, 16*(2), 171-203. https://doi.org/10.1108/APJIE-08-2022-0090