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PAPER

Preschool STEM Activities and Associated Outcomes: A Scoping Review

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ABSTRACT

This review highlights the need for further investigation into the benefits of STEM activities in preschool children's learning, girls' engagement and learning of children with disabilities in the STEM field. The review process involved accessing 19 relevant studies from Scopus, ERIC and Google Scholar databases in March 2023. Through the synthesis of information from these studies, seven STEM activities were identified as effective in enhancing preschool children's learning: educational robots, educational games, argumentative interactions, inquiry-based learning and engineering design, drawing and telling about engineers, free play and pretend play, and group membership. Each of these activities contributes to different learning outcomes for children. Moreover, the review emphasizes the importance of role-playing activities 'as if' engineers and scientists, facilitated by teachers, in fostering girls' motivation and engagement in the STEM field from an early age. Long-term scientific interventions at home have a significant positive impact on the science literacy skills of deaf children. The implications of this review are particularly relevant for early childhood educators, as it provides valuable insights into the use of STEM activities to enhance children's learning outcomes.

KEYWORDS

STEM, STEM education, preschool STEM activities, preschool children, children with disabilities, girls' engagement

1 INTRODUCTION

Although the idea of Science, Technology, Engineering, and Mathematics (STEM) education has been around for decades, the concept of STEM education was only officially stated by the US National Science Foundation in 2001 with the goal of firmly establishing the position of the United States as a world leader in economy, science and technology through improving human resources [1], [2]. Since then, STEM education has been increasingly recognized in the United States and globally as a basis for educational transformations that better prepare young people for college and STEM-related careers [1], [3]–[5]. The STEM approach offers an interdisciplinary

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perspective with a positive contribution to students' creativity, achievement, motivation, critical thinking, problem solving, and higher order skills [3], [6]–[8].

Most research in STEM education focuses on K-12 education levels [6], [9] [10]. However, a growing body of scholarly work has illuminated the significance of extending STEM education to the preschool phase, suggesting that preschool children may benefit from early STEM exposure [11]–[13]. It is believed that the early years are a valuable time to implement STEM education activities [14]. Early childhood STEM education can successfully meet the goals of the preschool curriculum [11]. Early childhood teachers are well aware the value of STEM education for children's learning and development [13]. Furthermore, both preschool children and their parents exhibit a favorable attitude towards STEM learning, perceiving it as a potential avenue for their children's future economic prosperity [13]. Within the framework of preschool STEM activities, children are empowered to acquire practical knowledge and skills while dealing authentic real-world challenges [11], [15]. Experiencing STEM-related tasks in childhood can foster in children original ideas about their STEM careers [14]. Preschool STEM activities can strengthen children's curiosity toward exploring the world around them and form the basis for all science studies throughout their lives [16]. Overall, with early exposure to STEM education, preschool children benefit from a variety of learning outcomes, such as developing problem-solving skills, cultivating curiosity in scientific discovery, and stimulating interest in STEM career pathways.

While many studies highlight the growing need to introduce children to STEM opportunities, some studies have raised concerns about gaps in STEM learning outcomes among preschool children, in which girls face more obstacles indeveloping STEM literacy, as well as expressing disinterest in pursuing STEM careers [17]. The lower likelihood of girls pursuing STEM-related careers may be related to traditional gender stereotypes [18]. These existing stereotypes can act as barriers for girls to develop an interest in STEM. The stereotypical belief that STEM is a male-dominated field will negatively impact girls' STEM experiences [19], [20]. When girls are negatively stereotyped in STEM, they may question their abilities and whether they are a good fit in the STEM field, making it harder for girls to develop STEM interests over time [21]. To close this gender gap, it is important to consider implementing STEM in the early stages of education, i.e. early childhood education [20]. Early participation in STEM activities is essential to ensure that girls are well-prepared for future STEM challenges [19], [20]. Therefore, researchers/educators should have effective interventions to redress gender disparities in STEM [21]. In addition to girls, other groups of children, such as those with dyslexia, deaf children, and blind children, may also be left out of STEM education due to learning challenges [22]. Children with disabilities are considered as a disadvantaged group in STEM education [22], [23]. They are often underrated in STEM learning in schools and the workforce compared with their peers without disabilities [23], [24]. Therefore, more efforts are needed to introduce preschool children with disabilities to such areas to encourage their interest in STEM [23], [24].

While a variety of interdisciplinary STEM activities have been implemented in early childhood education [13], to date, no studies have systematically investigated how STEM activities benefit preschool children's learning, including their extension to girls and children with disabilities. Therefore, the purpose of this scoping review was to investigate the implementation of preschool STEM activities and their impact on preschool children's learning.

Research questions:

1. In the existing research, what preschool STEM activities have been implemented to improve children's learning outcomes?

2. In the existing research, what preschool STEM activities have been implemented to promote girls' participation in the STEM field?
3. In the existing research, what STEM activities have been implemented to enhance the learning of children with disabilities in the STEM field?

2 METHODOLOGY

This study was a scoping review used to synthesize preschool STEM activities, and determine its effects on preschool children's learning outcomes. This work has provided information on preschool STEM activities and its associated outcomes for children, as well as developed theoretical inferences for future research in the preschool STEM field. The review was performed by four authors: VTH, BMH, DTTM and NVH.

The PRISMA flowchart [25] was utilized for screening studies (Figure 1).

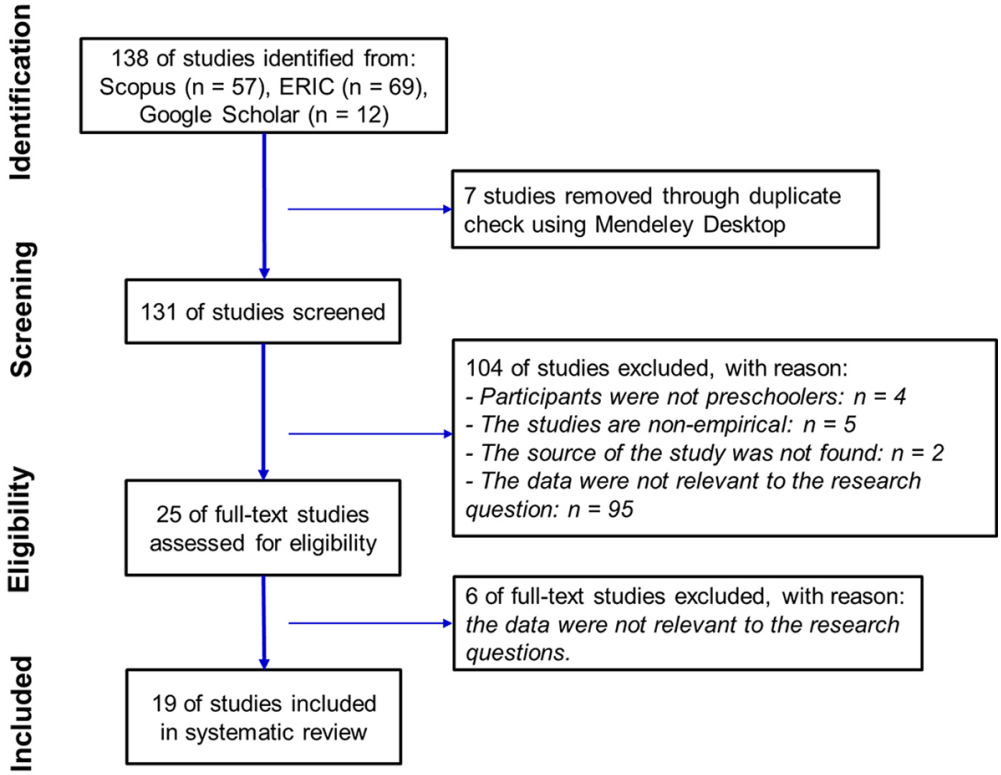

Fig. 1. Study selection process

2.1 Sources and search strategies

This scoping review used two prominent electronic databases, Scopus and ERIC, as the primary sources for the online inquiry, as illustrated in Figure 1. Among these repositories, Scopus is known as a prestigious database of high-quality scholarly research that is widely recognized in the scientific community [26]. Furthermore, we also used the Google Scholar database to search for additional studies in the first 200 to 300 results [27]. We identified 5 search keywords including "STEM", "STEAM", "Preschool", "Early children" and "Kindergarten". The search keyword string was defined as ("STEM" OR "STEAM") AND ("Preschool" OR "Early children"

OR "Kindergarten"). Within the Scopus database, we searched in the topic of the social sciences, the document type of the paper and conference paper, the English language. Within the ERIC database, we searched in the educational level of early childhood education, focusing specifically on descriptors of STEM education and preschool education.

2.2 Study selection

As illustrated in Figure 1, the study selection process was conducted through four distinct stages.

In the initial stage, identification, studies were identified in Scopus and ERIC in March 2023. A total of 138 studies were identified, with 57 from Scopus, 69 from ERIC and 12 from Google Scholar.

Subsequently, in the second stage, 138 studies were imported to Mendeley Desktop software to eliminate duplicates, resulting in the removal of 7 redundant studies.

Progressing to the third stage, the remaining 131 studies underwent meticulous evaluation based on their title, abstract, and keywords. This stage resulted in the exclusion of 106 studies. The rationales for their exclusion were as follows:

- Participants were not preschool children: n = 4
- The studies were non-empirical: n = 5
- Studies showing in Scopus and ERIC but not retrievable: n = 2
- The extracted data was not suitable for addressing research questions: n = 95

To neutralize the potential bias, both VTH and NVH authors participated in screening the studies. In case of any disagreements, two authors BMH and DTTM joined the discussion.

In the fourth stage, we conducted full-text readings of 25 potentially eligible studies. We excluded 6 studies due to the potential of the extracted data to be inappropriate to answer the research questions. As a result, 19 studies were included in the review.

To neutralize the potential bias, both VTH and NVH authors independently scrutinized the full-text studies during the fourth stage. They unanimously endorsed 18 of the 25 studies. Inter-rater reliability was gauged utilizing the conventional "percent agreement" methodology [28], resulting in a calculated percentage agreement of 0.72 (or 72%). A meeting involving four authors—VTH, BMH, DTTM and NVH—was convened to discuss the remaining seven studies until consensus was reached. Finally, we excluded 6 studies based on four-author consensus.

2.3 Data extraction

We extracted data focusing on preschool STEM activities and their impacts on children's learning outcomes. Additionally, we also extracted general information such as author, publication year, location, and participants. All four authors, VTH, BMH, DTTM and NVH, independently performed the data extraction from the full-text articles included in the review. Following the completion of data extraction, a meeting was held where author VTH presented her findings. The four authors

engaged in discussions until a consensus was reached regarding the extracted text segments.

3 RESULTS

3.1 Characteristics of the included studies

The data extracted from the 19 included studies were summarized in Table 1. In each included study, we summarized the information about the author's name, year of publication, place of publication, methodology, participants, and key findings.

Table 1. Data extraction of included studies

Author (s) (year)	Location	Methodology	Participants	Key Findings
Sullivan and Bers (2016) [29]	United States	Classroom-based research: 8-week KIWI robotics curriculum	60 children from kindergarten to grade 2	Preschool children are able to learn basic robotics and programming skills.
Master et al. (2017) [30]	United States	Within-subjects design: The effect of group membership on STEM engagement in preschool children	141 children (72 girls), 4.5 years old	Children's self-efficacy and interest in group STEM tasks were higher than in individual STEM tasks.
Solis et al. (2017) [31]	United States	Naturalistic observations in preschool classrooms: Spontaneous exploration of physical phenomena through 8-week object-play experiences	20 children (13 girls and 7 boys), 3–5 years old	Children acquire physical concepts as they plan and execute sequences of free play, problem-solving, and exploration with objects available in the classroom.
Dilek et al. (2020) [15]	Türkiye	Classroom observations, pre and post interviews: Inquiry-based STEM activities and engineering designs	14 children (7 girls and 7 boys), 5–6 years old	Inquiry-based STEM activities have enhanced the science process skills and engineering thinking of preschool children. Children have recognized science as a career area and are motivated towards science.
Alomyan et al. (2020) [32]	Jordan	Quasi-experimental approach: Mathematical Educational Games Program (11 sessions, 45 minutes per session)	55 children (25 boys and 30 girls), 5–6 years old	There was a significant difference between the control and experimental groups for children's development of number concepts in favor of the experimental group.
Convertini (2020) [33]	Italy	Video-recorded STEM tasks and discussions transcribed: Works with LEGO or recycled materials (16h of video-recordings)	25 children (13 boys, 12 girls), 4–8 years old	Cause-and-effect argumentative interactions prevailed in children. Children argued about complex aspects of the problem related to the scientific activity in which they participated.
Haber et al. (2021) [34]	United States	Naturalistic longitudinal classroom data: Conversations in an inquiry-based preschool classroom with a 3-week (14 hours) unit of force and motion	19 children, 3–5 years old	Providing opportunities to ask questions can motivate children to be more active in building knowledge. The causal questions occurred more during the first week, the information-seeking questions increased significantly in the second and third weeks.
Fleer (2021) [35]	England	Educational experiment: Girls' participation in STEM through a Conceptual PlayWorld for 12 weeks (123h of video-recordings)	9 children, 4–5 years old	Conceptual Play World engaged girls in the STEM conceptual spaces, and broke the gender divergence.
Rönkkö et al. (2021) [36]	Finland	Qualitative case study: video-recorded small-group sessions, field documentation (notes and photos)	19 children (9 girls and 10 boys), 5–6 years old	Investigative, playful activities through creative hands-on activities, such as designing and crafting, support preschoolers in learning everyday technologies.

(Continued)

Table 1. Data extraction of included studies *(Continued)*

Author (s) (year)	Location	Methodology	Participants	Key Findings
Fridberg and Redfors (2021) [37]	Sweden	Digital programming and robotics for learning STEM words (2h of video-recordings)	16 children, 4–5 years old	Digital programming and robotics supported children with a more varied use of programming and robotics words than the situation of programming without robots.
Fleer (2021) [38]	England	Digital observations, photographs of practices, interviews: Imagining of engineering by girls during free play 'as if' an engineer	31 children, 3.4–5.5 years old	In role-playing, girls have difficulty accessing and establishing engineering practices, and therefore have limited ability to act 'as if' an engineer.
Romero-Abrio et al. (2021) [39]	Spain	Educational experiment: Interaction between preschoolers and teachers while performing of physics and astronomy experiments	Not available	The early scientific competencies of preschool children were characterized by gender equality. Girls were not inclined towards science careers, even if they have the same scientific achievements as boys.
Stephenson et al. (2022) [20]	Australia	Educational experiment: Interactions and experiences within and outside the Conceptual PlayWorld (2-week observation period, 13h of video-recordings)	13 children (6 girls and 7 boys), 2–3 years old	In free play environments, girls often stay away from STEM activities. These are minimized inside the Conceptual Play World with teacher support.
Ata-Aktürk and Demircan (2022) [40]	Türkiye	Phenomenography: How preschool children perceive engineers and engineering by using their drawings and explanations	436 children, 4–6 years old	Through drawings, most children tended to view engineering as physical work and exclusively for men, with activities of working outdoors, building construction or making machines.
Hollenstein et al. (2022) [41]	Switzerland	Exploratory intervention study: Play corners for pretend play with smart home (IoT) or autonomous vehicles (13 hours)	15 children	Children identified problems in a pretend play situation and solved them using problem-solving strategies, such as inventing new applications and installing software.
Jones et al. (2022) [42]	England	Long-term interventions in science learning at home for about 13 months	26 children (10 girls and 16 boys) with 12 deaf children	Long-term science interventions at home can close the gap in science inquiry skills between children with hearing loss and children with normal hearing.
Akcay Malcok and Ceylan (2022) [43]	Türkiye	Pre-test/post-test experimental design: STEM activities 3 days a week for 8 weeks	36 children	STEM activities make a significant difference in the problem-solving skills of preschoolers.
Akpinar and Akgunduz (2022) [44]	United States	Case study: STEM applications for 12h in 8 weeks	20 children (9 boys and 11 girls) 5 years old	STEM applications increased children's interest in STEM fields, given them new knowledge about STEM, and promoted efficiency in their product design process.
Tanik Onal and Saylan Kirmizigul (2022) [16]	Türkiye	Educational experiment: Using the Kit Makey-Makey and Scratch programming in the activity titled "Learning with Seasons" (4 course hours)	24 children, 4–5 years old	STEM activities facilitated preschool children to achieve science learning goals and established an environment for children to have fun while learning.

3.2 Years of publication

Table 1 provided detailed information on the characteristics of the 19 included articles. When examining the publication year of the 19 articles included, interesting patterns were observed (Figure 2). The earliest publication among the included articles was in 2016 [29]. Two articles were published in 2017 [30], [31]. There were

no articles published in 2018 and 2019. However, starting from 2020, the number of articles published each year increased rapidly. In 2020, there were 3 articles published [15], [32], [33]. In 2021, there were 6 articles published [34]–[39]. The year 2022 saw the highest number of publications with 7 articles [16], [20], [40]–[44].

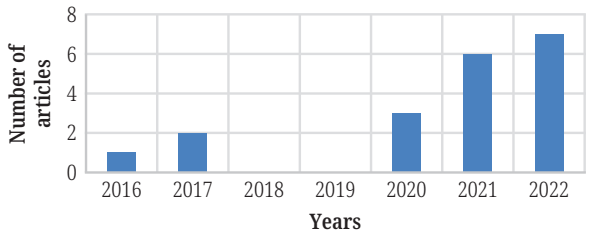

Fig. 2. Years of publication

3.3 Research locations

Regarding the geographical distribution, as illustrated in Figure 3, the included articles were conducted in various countries. The United States [29]–[31], [34], [44], Türkiye [15], [16], [40], [43] were the two countries with the highest number of articles included. Additionally, studies were conducted in Italy [33], England [35], [38], [42], Finland [36], Sweden [37], Spain [39], Switzerland [41], Australia [20], Jordan [32]. The studies were predominantly carried out in Europe, the United States and Türkiye. In general, the majority of studies are conducted in developed countries.

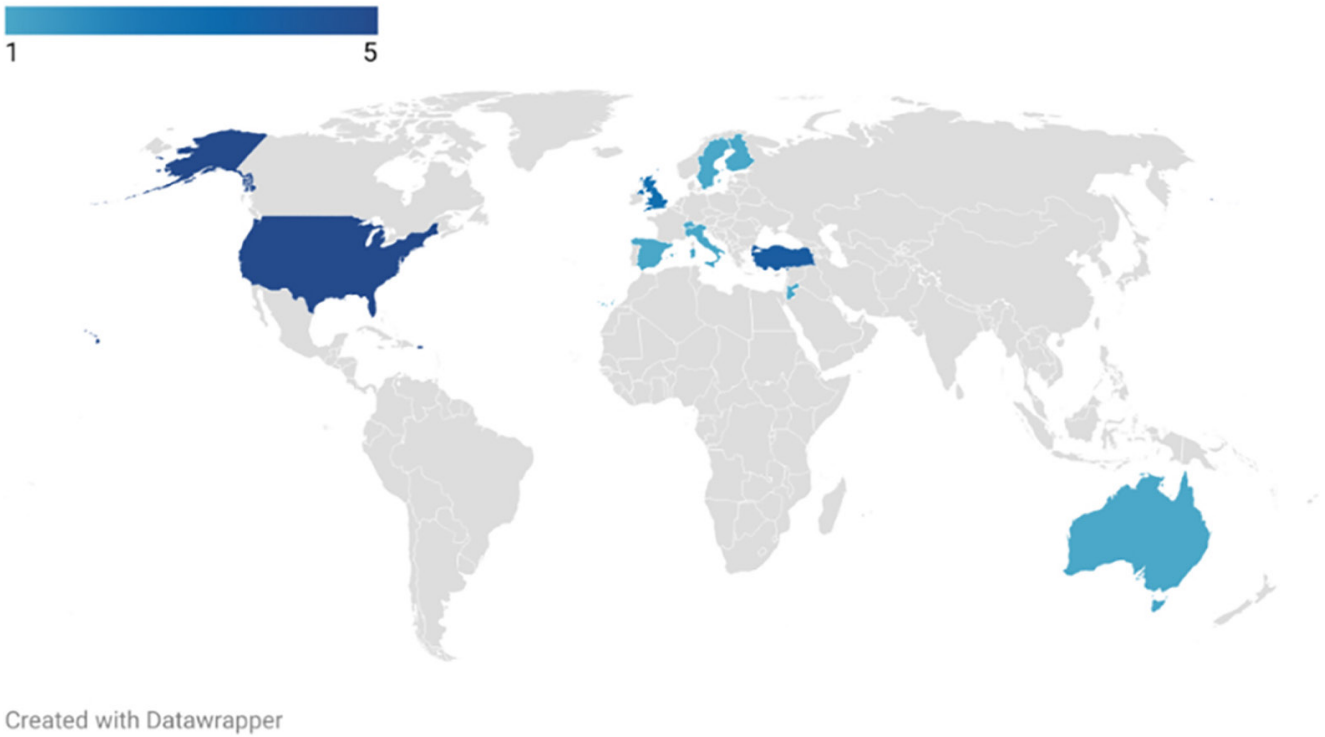

Fig. 3. Geographical distribution of articles (image created with datawrapper)

3.4 Participants

Regarding participant characteristics, as indicated in Table 1, the sample sizes in the included studies were generally small, with 15 out of the 19 studies having less than 50 participants. The children included in the studies were typically between the ages of 2 and 8 years old. The proportion of boys and girls participating in the studies was similar across most of the included studies. There were 12 deaf children participating in one study [42].

3.5 Preschool STEM activities and children's outcomes

In Table 2, we presented preschool STEM activities related to the research question. Specifically, there were 14 articles that focused on preschool STEM activities aimed at improving children's learning outcomes. The STEM activities mentioned in those studies included educational robots [16], [29], [37], educational games [32], argumentative interactions [33], [34], inquiry-based learning and engineering design [15], [36], [43], [44], drawing and telling about engineers [40], free play and pretend play [31], [41], group membership [30]. Overall, there was a wide variety of STEM activities that improve preschool children's learning.

Regarding girls' participation in the STEM field, two themes emerged from the literature. The first theme was role-playing "as if" engineers and scientists, which was found in studies [20], [35], [38]. The second theme focused on scientific experiment, and it was explored in studies [39]. Lastly, one study examined the impact of long-term scientific interventions on the learning of children with disabilities in the STEM field [42]. This study specifically investigated how children with disabilities can benefit from STEM interventions and improve their learning outcomes.

Table 2. Preschool STEM activities and children's outcomes

Preschool STEM Activities	Children's Outcomes
Research question 1: In the existing research, what preschool STEM activities have been implemented to improve children's learning outcomes?	
– Educational robots	Learning goals in science curriculum [16]; motivation [16]; robotics and programming skills [29]; programming and robotics words [37]
– Educational games	Number concepts [32]
– Argumentative interactions	Cause-and-effect interactions in natural science [33], [34]; motivation [34]
– Inquiry-based learning and engineering design	Science process skills [15]; engineering thinking [15]; motivation towards science [15]; learning everyday technologies [36]; problem-solving skills [43]; interest in STEM fields [44]; learning efficiency [44]
– Drawing and telling about engineers	Children's perception of engineering careers [40]
– Free play and pretend play	Physical concepts [31]; problem-solving skills [41]
– Group membership	Children's self-efficacy and interest in group STEM tasks [30]
Research question 2: In the existing research, what preschool STEM activities have been implemented to promote girls' participation in the STEM field?	
– Role-playing activities 'as if' engineers and scientists	Girls' STEM engagement [20], [35], [38]; gender divergence [35]
– Scientific experiment	Scientific competencies [39]
Research question 3: In the existing research, what STEM activities have been implemented to enhance the learning of children with disabilities in the STEM field?	
– Long-term interventions in science learning at home	Science inquiry skills of deaf children [42]

4 DISCUSSION

4.1 Research Question 1: In the existing research, what preschool STEM activities have been implemented to improve children's learning outcomes?

Reviewing the extracted data from the fourteen articles, we identified seven preschool STEM activities that have been implemented to improve children's learning outcomes. These activities were as follows: (1) educational robots, (2) educational games, (3) argumentative interactions, (4) inquiry-based learning and engineering design, (5) drawing and telling about engineers, (6) free play and pretend play, (7) group membership. These activities have been explored in the reviewed studies as effective means to enhance children's learning outcomes in the preschool STEM context.

Educational robots. The three reviewed articles highlighted the benefits of educational robots in enhancing children's learning in the STEM field [16], [29], [37]. These studies focused on using educational robots to develop children's knowledge of robotics and programming concepts/skills [29], [37], improve learning achievement in science and establish an active learning environment for preschool children [16]. For example, a study employed the KIWI robotics kit and a tangible programming language in an 8-week robotics curriculum involving 60 children from preschool to 2nd grade [29]. The results showed that starting in preschool, children were able to master programming skills and basic robotics knowledge [29]. Older children demonstrated the ability to understand more complex concepts using the same robotics kit within the same timeframe [29]. Another study utilized the Makey-Makey kit and the Scratch programming language in a STEM activity called "Learning with Seasons" with 24 children aged 48–60 months [16]. The results showed that the use of these tools facilitated children's engagement with science education and created an enjoyable learning environment [16]. It helped children achieve the learning objectives in science education while having fun [16]. In another study, Fridberg combined educational robots and digital programming to enhance children's flexibility in using robot-related words [37]. The findings indicated that the use of educational robots promoted children's ability to employ robot words more flexibly than the situations without robots [37]. Overall, the existing evidence highlight the promising potential of educational robots in enhancing children's educational journeys within the field of STEM. However, the existing research only reports opportunities for children to acquire foundational knowledge of robotics, cultivate programming skills, and enjoy a fun learning experience. Therefore, a more cautious approach is needed to understand the impact of educational robots on children's other STEM learning outcomes.

Educational games. One reviewed study examined the effects of educational games on the development of number concepts in preschool children aged 5 to 6 years [32]. Through a semi-experimental design, involving an experimental group of 29 children and a control group of 26 children, the researchers aimed to investigate the impact of educational games on children's number concept development [32]. The findings revealed a significant difference in the development of number concepts between the two groups, with the experimental group displaying a higher level of development compared to the control group [32]. This suggests that the use of educational games can positively influence the acquisition and understanding of number concepts in preschool children. Furthermore, the study highlighted the role of educational games in promoting learning motivation in mathematics of preschool children. It was found that educational games effectively enhanced children's

motivation to engage with mathematical concepts and activities [32]. Therefore, educational games can be a valuable tool to enhance motivation and achievement in the early mathematics education of preschool children. However, as with any semi-experiments, certain biases or uncontrolled variables might impact the observed differences. Furthermore, the short duration of exposure in educational games could also play a role in influencing the observed outcomes.

Argumentative interactions. Two studies investigated the role of argumentative interactions in early childhood STEM activities for the development of children's critical thinking and scientific reasoning [33], [34]. In one experimental study, 25 preschool children (mean age: 4 to 8 years) engaged in problem-solving tasks involving building structures using LEGO (building a tunnel and a bridge) and recycled materials (building an hourglass), and their argumentative interactions were analyzed [33]. The findings revealed the prevalence of cause-and-effect arguments, indicating how children reasoned and discussed complex aspects of the tasks, such as the potential negative consequences of actions and the suitability of tools for the scientific activities involved [33]. This suggests that STEM activities, particularly in the context of free play, have the potential to enhance children's critical thinking abilities through argumentative interactions in scientific contexts.

Another study focused on observing children's argumentative interactions in an inquiry-based classroom setting during a three-week unit on "force and motion", with teacher involvement [34]. The study examined the nature of questions posed by both teachers and children and analyzed naturalistic longitudinal data. The findings indicated that the majority of information-seeking questions were teacher-posed and fact-based [34]. While more causal questions occurred in the early weeks, more fact-based questions were asked at the end of the investigation [34]. Notably, children's information-seeking questions significantly increased during weeks 2 and 3, indicating their growing engagement and active role in constructing scientific knowledge [34]. This suggests that providing opportunities for children to ask questions fosters their active involvement in scientific inquiry and knowledge construction. Overall, these studies collectively underscore the crucial role of argumentative interactions in fostering critical thinking and scientific reasoning among preschool children. However, it is crucial to acknowledge the potential influence of pedagogical strategies and classroom dynamics on the observed shifts in question types.

Inquiry-based learning and engineering design. Four reviewed studies examined the combination of inquiry-based learning and engineering design in early childhood STEM education, highlighting its positive impact on various aspects of children's learning outcomes [15], [36], [43], [44]. These studies consistently demonstrated that STEM activities through inquiry-based learning and engineering design enhance learning motivation, science processing skills, problem-solving abilities, and interest in STEM fields among preschool children [15], [36], [43], [44]. For example, one experimental study involved 14 children aged 5 to 6 years and implemented four STEM activities through inquiry-based learning and engineering design, related to the topic "force" in solids, liquids and gases [15]. The findings indicated that children actively engaged in these STEM activities and demonstrated the utilization of science process skills [15]. Furthermore, children developed a perception of science as a field of activity and exhibited motivation towards science [15]. In another study, the combination of inquiry-based activities with hands-on experiences, such as design and crafting, created an exploratory and playful learning environment for preschool children to learn about everyday technologies [36]. It also facilitated children's understanding of technological processes and their ability to transfer knowledge from one situation to another [36]. Additionally, it fostered children's

interest in STEM fields, provided them with new insights into engineering careers, and enhanced their efficiency in the process of designing and inventing products [44]. Overall, the combination of inquiry-based learning and engineering design in early childhood STEM activities offers many benefits to preschool children in terms of understanding, motivation, interest, science process skills, and problem-solving.

Drawing and telling about engineers. One reviewed study investigated the effects of the draw-and-tell technique, involving drawing and explaining an engineer, on the perceptions of 436 preschool children (ages 4–6 years old) [40]. The findings revealed diverse understandings and perceptions of engineering and engineers among the participating children. Notably, some children (n = 50) did not demonstrate any understanding of engineering or engineers in their drawings [40]. The majority of children (n = 199) tended to associate engineering with physical labor typically performed by men, particularly when working outdoors [40]. Many children (n = 156) depicted engineering as activities related to building buildings or making machines [40]. While this study offers valuable insights, it is essential to consider certain limitations such as the research context and cultural influences of the place where the study was conducted, in Türkiye. Therefore, further studies should be done to confirm how drawing and telling about an engineer can influence preschool children's perception of engineering practice.

Free play and pretend play. Two reviewed studies highlighted the benefits of free play and pretend play activities in STEM education for preschool children's learning [31], [41]. These studies emphasized the idea that engaging in STEM activities through playing with objects can enhance children's understanding, achievement, and problem-solving skills. In an experimental study, the spontaneous explorations of 20 young children regarding physical phenomena were investigated during an 8-week period of playing with objects [31]. The findings revealed that as children engaged in activities involving planning and executing sequences of games, problem-solving, and exploring with objects in the classroom, they were exposed to a wide range of physical concepts, including magnetism, force, energy, tension, friction, and simple machines [31]. This suggests that free play activities provide valuable opportunities for children to actively interact with the physical world, and foster their understanding of fundamental STEM concepts. Similarly, another study focused on the role of pretend play in the corners of smart homes (IoT) or autonomous vehicles in the classrooms of 15 preschool children with 13 hours of study [41]. The findings indicated that through pretend play, children identified problems within the play situations and utilized problem-solving strategies, such as inventing new applications and installing software, to address these challenges [41]. Thus, the combination of these forms of play with STEM subjects is not only enriching the foundational concepts but also training problem solving and stimulating creative thinking in children. Educators are presented with an engaging avenue to leverage children's inherent curiosity and creativity, and thereby harness the power of play to nurture children's abilities and passions in the STEM area. However, the need to consider variations in play experiences, individual preferences and contexts of play-based learning remains crucial.

Group membership. One reviewed study explored the influence of group membership on the level of STEM participation among preschool children (N = 141; 4.5 years old) [30]. The children were bifurcated into two distinct conditions: a collective group scenario and an individualized context. Then, they were tasked with undertaking both a mathematical exercise and a spatial puzzle exercise. The mathematical task required children to pair cards, with one card displaying a numeral (e.g., "6") and the accompanying card detailing the corresponding number of objects,

such as six bluebirds. Initially, the children faced a set of numbers from 6 to 15, and if they finished ahead of time, they were assigned a more challenging set of numbers, from 16 to 20. Meanwhile, the spatial puzzle assignment entailed assembling a moderately intricate animal puzzle comprising 12 interlocking pieces that collectively formed the depiction of a duck. Similarly, children were given a second, more difficult puzzle task, if they finished the first puzzle task. The findings indicated that children exhibited a higher level of self-efficacy and interest in the group STEM task [30]. This suggests that incorporating the factor of group membership into STEM programs can effectively promote STEM motivation among preschool children. By providing opportunities for collaborative and cooperative learning experiences within a group setting, children may feel more confident, engaged, and motivated to participate in STEM activities. However, it is essential to consider a broader range of motivational factors that might contribute to the observed effects of group participation.

4.2 Research Question 2: In the existing research, what preschool STEM activities have been implemented to promote girls' participation in the STEM field?

Role-playing activities 'as if' engineers and scientists. Three reviewed studies investigated girls' engagement in STEM activities. These studies explored the use of Conceptual Play World and role-playing activities to enhance girls' motivation and engagement in the STEM field. In these studies, girls were encouraged to play 'as if' engineers and scientists. The findings from these studies indicated that Conceptual Play World was an effective approach to engage girls in the STEM field [20], [35]. It provided an active and interactive learning environment where girls actively participated in STEM conceptual spaces, while gender interactions and divergences were minimized [20], [35]. By immersing girls in the role of engineers and scientists, the Conceptual Play World facilitated their motivation and engagement in STEM learning. However, one study noted that girls faced challenges in establishing engineering activities during free play [38]. In the free-play environment, girls stayed away from STEM activities, but this was minimized within the Conceptual Play World with the active role and involvement of the teacher [20]. The role of the teacher in facilitating and supporting girls' participation played an important role in fostering their motivation and engagement in the STEM field [20]. Overall, the findings suggest that role-playing activities, such as playing 'as if' engineers and scientists within the context of Conceptual Play World, along with teacher facilitation, can effectively promote girls' motivation and engagement in STEM from an early age. It helps to overcome gender-related barriers and encourages girls to actively participate in STEM activities, and cultivates their interest and enthusiasm in the STEM field.

Scientific experiment. One reviewed study investigated examined gender differences in the scientific competence of preschool children by observing interactions between children and teachers during physics and astronomy experiments. The results found that there were no significant gender differences in scientific competence [39]. This suggests that boys and girls have similar abilities and skills in scientific domains during the preschool years. However, despite similar scientific competencies, the study revealed that girls may not be as inclined towards science careers as boys [39]. This indicates that gender differences may manifest in children's attitudes and aspirations towards STEM fields, rather than in their actual competencies. It highlights the importance of addressing gender-related stereotypes and biases to promote equal opportunities and encourage girls' participation in

STEM disciplines. Overall, the findings indicate that there are no significant gender differences in STEM competencies among preschool children in the context of scientific experiments. However, it is important to address gender-related attitudes, perceptions, and biases to create an inclusive environment that encourages all children, regardless of their gender, to pursue in STEM fields. By promoting positive attitudes towards STEM and addressing gender stereotypes, we can foster equal opportunities and aspirations for boys and girls in the STEM disciplines.

4.3 Research Question 3: In the existing research, what STEM activities have been implemented to enhance the learning of children with disabilities in the STEM field?

One reviewed study focused on enhancing the learning of children with disabilities, specifically deaf children, in the STEM field [42]. This study involved caregivers of deaf children (n = 17) implementing a long-term scientific intervention at home, which incorporated the language of science into the children's daily routine [42]. Over a 13-month period, caregivers actively engaged deaf children in science-related activities. The findings indicated that deaf children showed greater acquisition of scientific inquiry skills compared to children with normal hearing [42]. This suggests that the long-term scientific intervention had a positive impact on the science concepts and inquiry skills of deaf children, potentially narrowing the achievement gap between deaf children and their peers with normal hearing. By incorporating science language and activities into their daily routine, caregivers can create an enriched learning environment that promotes the development of science concepts and inquiry skills in deaf children. These interventions have the potential to provide equal opportunities for learning and contribute to bridging the achievement gap in STEM education for children with disabilities.

5 CONCLUSION

This study aimed to examine existing research on STEM activities that promote preschool children's learning outcomes, encourage girls' participation, and enhance learning for children with disabilities. The findings revealed seven STEM activities that have the potential to improve preschool children's learning outcomes. These activities include educational robots, educational games, argumentative interactions, inquiry-based learning and engineering design, drawing and telling about engineers, free play and pretend play, and group membership. Each of these activities contributes to different aspects of children's learning. Additionally, it highlighted the significance of role-playing activities 'as if' engineers and scientists, facilitated by teachers, in fostering girls' motivation and engagement in the STEM field from an early age. It was also found that there was no gender difference in the STEM competencies of preschool children in the context of scientific experiments, suggesting that both boys and girls have equal potential in STEM learning. Furthermore, the study emphasized the effectiveness of long-term scientific intervention at home for improving the science literacy skills of deaf children. Overall, this study successfully achieved its intended purpose of exploring STEM activities that benefit preschool children's learning, encourage girls' participation, and enhance learning for children with disabilities. Early childhood teachers can directly benefit from the findings of this study as they incorporate STEM activities into their teaching practices, aiming to improve preschool children's learning experiences and outcomes.

It is important to acknowledge the limitations of this review in order to interpret the findings accurately. Firstly, one limitation is that all the included articles in this review were sourced from Western and developed countries. As a result, the findings may not fully capture the experiences and outcomes of STEM activities in other specific cultural and geographical contexts. It is recommended that future studies explore STEM activities in diverse local contexts to provide a more comprehensive understanding of their impact on preschool children's learning. Secondly, the review did not include articles from the Web of Science due to restricted access for the researchers. This limitation may raise questions about the potential exclusion of relevant high-quality research. Future studies should attempt to access the Web of Science database to further expand this review.

Based on this scoping review, we observed several future directions. Firstly, the number of experimental studies on the impact of STEM education on preschool children's learning was scarce (n = 19), especially studies involving girls in STEM and children with disabilities. The sample size in most studies was less than 50 children. Therefore, more experimental studies should be conducted with larger sample sizes in future studies. Secondly, it is recognized that new knowledge in science is often created by interpreting and combining existing concepts [45]. As a result, researchers can construct new ideas for preschool STEM activities by combining knowledge from existing studies. For example, argument-based and inquiry-based learning can be incorporated into preschool STEM education, as found in a recent study [7].

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