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Exploring cognitive skill development in STEM education for kindergarten children: A systematic review

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Abstract

This systematic review study aims to examine the effects of science, technology, engineering, and mathematics (STEM)/science, technology, engineering, arts, and mathematics (STEAM) education on cognitive skill development in early childhood. The research was carried out following the five-stage framework in line with the preferred reporting items for systematic reviews and meta-analyses guidelines. In the first scan carried out on 15 June 2025 in the *Web of Science* and *Scopus* databases, 614 studies were reached, and 36 studies were included in the analysis after the duplication, removal and inclusion criteria were applied. Data analysis was carried out by document analysis method, frequency and categorical analyzes were performed using descriptive analysis techniques. The reliability level of the study was calculated as 85% with the Miles and Huberman formula. The findings reveal that the number of publications in this field has increased remarkably by reaching 15 in 2025. 89% of the studies were in the type of articles and were mostly published in the *Education Sciences*. It determined that STEM/STEAM education supports various cognitive skills such as problem-solving (n = 10), creativity (n = 10), critical thinking (n = 5) and comprehension (n = 8). Game-based, inquiry-based and project-based learning approaches have been shown to have positive effects on cognitive flexibility and creative thinking. Technology-based tools develop digital literacy and algorithmic thinking skills, manipulative materials develop spatial intelligence and motor skills, and makerspace environments develop creativity and innovation skills. It has been determined that family participation strengthens the cognitive development of children with STEM support, school-family cooperation and emotional support dimensions in the home environment. In this context, suggestions were made to researchers to conduct multidimensional and long-term studies, to effectively implement game-based, project-based and technology-supported pedagogical approaches to teachers, and to strengthen digital and physical learning infrastructure with inclusive, equitable and sustainable programs for education policy makers.

Keywords: early childhood education, STEM education, cognitive skill development, systematic review

INTRODUCTION

The 21st century is defined by rapid transformations in social, scientific, and technological fields, and these developments reshape the knowledge, skills, and competencies that individuals should possess in the educational process (Geisinger, 2016). In this context, the implementation of science, technology, engineering, arts and mathematics (STEAM) education with a holistic approach, especially in the preschool period (3-6 years), is seen as a critical period skill for future learning (Beisly & Moffitt, 2024). Science, technology, engineering, and mathematics (STEM)/STEAM education not only provides children with the opportunity to explore abstract concepts but also provides them with the cognitive and analytical skills necessary to solve complex problems they will encounter (Wu et al., 2024).

Many countries have focused on STEM/STEAM education with the aim of developing children's 21st century skills (Zhou & Yang, 2024). In countries such as

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Contribution to the literature

- This study provides a comprehensive synthesis of 36 empirical studies, highlighting the multidimensional impact of STEM/STEAM education on the development of cognitive skills in kindergarten-aged children.
- It identifies key pedagogical approaches—such as play-based, inquiry-based, and project-based learning—that effectively foster problem-solving, creativity, and critical thinking in early childhood education.
- By addressing gaps in the existing literature, particularly in non-Western contexts and the integration of computational thinking, the review offers actionable insights for educators, researchers, and policymakers seeking to enhance early STEM/STEAM practices.

the United States, Canada, the United Kingdom, China, Germany, Japan, South Korea, Singapore, Sweden, Finland, the Netherlands, Norway, Denmark, Australia, New Zealand, and Hong Kong, STEM materials and toys are integrated into the preschool curriculum (Yang et al., 2025). These toys are seen as effective tools in the acquisition of STEM skills and open the door to a multifaceted development process in children (He et al., 2021; Wenz-Gross et al., 2018). In addition, teaching methods and environments such as game-based STEM learning support children's cognitive and social development in different ways (Pyle & Bigelow, 2015). Preschool is one of the stages in which children's natural curiosity and exploration tendencies are most intense (Simoncini & Lasen, 2018). In this context, there has been a significant increase in recent years in research on the development of basic cognitive skills such as problem-solving, critical thinking, creativity, and logical reasoning in STEM education (Beisly & Moffitt, 2024; Buchter et al., 2017; Israsena et al., 2016; Ludwig et al., 2016; Perignat & Katz-Buonincontro, 2019; Uyanık Balat & Günşen, 2017).

The contribution of STEM/STEAM education to cognitive skill development in early childhood is emphasized in many studies. STEM/STEAM education, especially in preschool children; It is an important learning approach that supports basic skills such as problem-solving, critical thinking, creativity, logical reasoning, attention, memory, and language development (Pandey, 2025). Inquiry-based activities have led to remarkable improvements in children's ability to understand abstract concepts, use tools, design experiments, solve problems, and collaborate (Wang & Chen, 2025). Similarly, design-oriented STEM education has permanently increased children's creativity and problem-solving abilities (Yalçın & Erden, 2021). In addition, maker-based learning environments have been shown to improve STEM thinking habits, support socio-emotional skills, and prepare children for the digital future (Yang et al., 2025). However, the development of cognitive skills is a multidimensional process and elements such as applied pedagogical approaches, organization of the classroom environment and parental participation directly affect this process. Teachers play a facilitating and mediating role in children's learning experiences through STEM toys; It supports analytical thinking and problem-solving skills by encouraging experimentation (Pandey, 2025).

Although there are more and more studies on the effects of STEM/STEAM education on cognitive skills in preschool, there are still significant research gaps. In particular, there is limited evidence regarding the impact of certain teaching strategies on children's cognitive, social, and emotional outcomes (Pandey, 2025). Furthermore, some research points to the lack of strong empirical evidence that the STEAM approach offers a distinct advantage over STEM in terms of enhancing creativity (Aguilera & Ortiz-Revilla, 2021). Although it has been suggested that maker-based learning environments can enhance teachers' STEM competencies, data on the effects of such practices on preschool children, especially in non-Western contexts (e.g., Asia) are limited (Yang et al., 2025). The lack of pedagogical knowledge of how teachers can consciously support early childhood STEM learning is also a significant gap area (Simoncini & Lasen, 2018). This is further accentuated by the paucity of research on programming and computational thinking (CT) teaching in early childhood (Zeng et al., 2023). Teachers' lack of limited knowledge, experience and positive attitudes about coding education is also noteworthy (Ergin, 2020). In some Eurasian countries, the lack of systematic implementation of STEM education in early childhood education and the inadequacy of initiatives weaken this field (Bardak& Polat, 2019; Yang et al., 2025; Zeng et al., 2023). In addition, the CT approach has not yet been integrated into many preschool programs (Avcı & Deniz, 2022; Kanaki & Kalogiannakis, 2022). In this context, this systematic review aims to address these research gaps and comprehensively examine the effects of factors such as how cognitive skills are handled, teaching strategies, classroom environment, and parental involvement on cognitive skills.

The main purpose of this study is to systematically examine the effects of STEM/STEAM education on cognitive skill development in preschool (especially kindergarten age). By examining the current studies in the literature, it has been revealed how basic and high-level skills such as problem-solving, critical thinking, creativity, logical reasoning, attention, memory and language development are supported by STEM/STEAM-oriented learning processes. In addition, the effects of variables such as teaching strategies, learning environment and parental involvement on this process were evaluated. In this context, answers to the following research questions were sought.

1. What cognitive skills of kindergarten children is STEM/STEAM education research based on?
2. How do the effects of STEM/STEAM activities applied in early childhood on cognitive development differ according to the pedagogical approaches applied?
3. What is the contribution of the classroom environment and learning materials to the development of cognitive skills?
4. How do family involvement and parental support shape the effects of STEM/STEAM practices on the cognitive development of kindergarten children?

THEORETICAL BACKGROUND

STEM/STEAM Education

The concept of STEM consists of the initials of the disciplines of science, technology, engineering and mathematics and refers to the handling of these fields within the framework of an integrated learning approach (Abu Khurma et al., 2022; Tavdgiridze et al., 2024). This understanding has come to the fore when traditional single-discipline teaching models are insufficient to develop the interdisciplinary skills necessary to solve complex and real-life problems (Zhan et al., 2025). The main purpose of STEM education is not only to provide individuals with academic knowledge; at the same time, it is to equip them with skills such as critical thinking, problem-solving, creativity, adaptability, cooperation and leadership needed in the 21st century (Turiman et al., 2012). Therefore, STEM is considered not just a field or topic, but a pedagogical approach that builds the learning process on collaboration and problem-solving methods (Razali & Rahman, 2021).

This approach offers an innovative structure that integrates the four disciplines into a common teaching paradigm by eliminating traditional boundaries (Bybee, 2010; Ejiwale, 2013). Such an integrative perspective supports students' learning processes by connecting different disciplines in authentic learning contexts (Kelley & Knowles, 2016). Over time, with the addition of the discipline of arts to STEM, the STEAM model has been developed and the function of art in the learning process has become more visible (Sousa & Pilecki, 2013). The inclusion of art in this process has enabled the integration of scientific and artistic processes within the framework of creative problem-solving and has provided students with richer learning experiences (Bequette & Bequette, 2012). For example, both scientific and artistic processes aim to develop creative solutions by starting with a question or problem (Mercan & Kandır, 2024). For this reason, STEAM is seen as an educational approach that aims to transform the way individuals think (Baek & Yoon, 2016).

The philosophical aspect of STEM is also associated with Gardner's theory of multiple intelligences. Gardner argues that skills such as creativity, critical thinking, problem-solving, and collaboration, which he defines as universal literacy, are the basic conditions for individuals to survive in the 21st century. According to him, it is a critical requirement that children be equipped with skills that machines cannot do in the future. In this context, the importance of using scientific knowledge in developing new products through technology and engineering is emphasized (Yalçın & Erden, 2021). STEM education offers individuals a multi-faceted development opportunity rather than being a process based only on knowledge transfer (Israsena et al., 2016). Introducing children to science with well-planned programs, especially from the preschool period, contributes to their growth as individuals who can adapt to changing living conditions (Thanh et al., 2025). The STEAM approach, on the other hand, makes significant contributions to the growth of students as creative, critical thinkers, problem solvers, effective communicators and technology literate individuals (Buchter et al., 2017; Israsena et al., 2016; Ludwig et al., 2016; Perignat & Katz-Buonincontro, 2019; Uyanık Balat & Günşen, 2017). It is also reported that such programs improve students' abstract thinking skills and increase their capacity to cope with the challenges encountered (Wu et al., 2024).

On the other hand, STEM can be applied with different approaches. The three most commonly used approaches in the literature are siloed, embedded, and integrated (Mercan & Kandır, 2024; Morrison, 2006; Roberts & Cantu, 2012; Sanders, 2009). While the silo approach focuses on in-depth learning by considering each discipline separately (Mercan & Kandır, 2024; Morrison, 2006; Roberts & Cantu, 2012; Sanders, 2009), the embedded approach aims to teach STEM knowledge by associating it with social, cultural, and functional dimensions (Basaran & Bay, 2023; Chen, 2009). The integrated approach, on the other hand, aims to create a holistic learning space by eliminating the boundaries between disciplines (Sanders, 2009).

One of the important models that strengthens the pedagogical framework of STEM is the 5E teaching model. Based on constructivist learning theory, this model allows students to relate their existing knowledge to new knowledge and participate in active learning processes (Bybee, 2014; Wang et al., 2025). Stages of the model; It consists of attention, discovery, explanation, deepening and evaluation processes and supports critical thinking (Bilgin et al., 2016). Another application that has come to the fore in recent years is makerspace-based STEM education. This approach helps students develop their STEM habits (HoMs) and support their emotional well-being. Makerspace environments allow for the development of a wide range of HoMs with their collaborative and multi-disciplinary structure. These habits encompass components such as scientific process skills, coding, and engineering practices (Yang et al., 2023). Communication, collaboration, critical thinking and creativity, which are among the 21st century skills, are evaluated within the scope of universal literacy and it is stated that these skills can be supported by design-oriented thinking processes (Yalçın & Erden, 2021). Design thinking, especially in preschool STEM practices, encourages children's active participation in both problem-solving and product development processes (Dam & Siang, 2018a, 2018b). In this respect, STEM allows children to explore the world in innovative ways and solve the problems they encounter creatively (Affifi, 2019).

STEM education is at the heart of education reforms on a global scale, aiming to equip individuals with the interdisciplinary skills necessary to solve complex problems (Wang et al., 2025). When applied from an early age, it contributes to children's knowledge and skills in the fields of science, technology, engineering and mathematics; with the inclusion of art, it offers a more creative and holistic learning process (Su et al., 2025).

STEM/STEAM and Early Childhood

Early childhood is a period in which children's mental flexibility, perception and creativity capacities are at the highest level and is considered critical for intelligence development (Dufranc et al., 2020). For this reason, STEM-based education is of great importance in terms of providing a solid foundation for children's progressive learning processes, especially in the preschool years (Buchter et al., 2017; DeJarnette, 2018; Ludwig et al., 2016; McClure et al., 2017; Sharapan, 2012; Tank et al., 2018). It is often emphasized that quality early practices create a strong foundation for children's future academic and cognitive development (DeJarnette, 2018; Keulen, 2018; Ludwig et al., 2016; Sharapan, 2012). In this process, kindergarten teachers are key variables that facilitate children's play experiences through STEM toys and materials. Through their role as guidance and mediator, teachers increase children's participation in collaborative work, encourage them to experiment, and allow them to learn from mistakes (Pandey, 2025). In this context, it has been reported that teachers' approaches to such materials are generally positive and this supports cognitive skills such as problem-solving and critical thinking, as well as social-emotional aspects such as verbal communication. There are findings that STEM practices carried out in preschool provide permanent and positive effects on children's creativity and problem-solving competencies (Akçay Malçok & Ceylan, 2022). In particular, design-oriented STEM activities improve children's communication and interaction skills, contribute to peer learning, reinforce self-confidence, cooperation, and a sense of responsibility, and encourage empathy, idea generation, and problem-solving processes (Yalçın & Erden, 2021).

It is known that the preschool period covers 36-72 months and is one of the most productive periods in terms of brain development (Tutku & Sengul, 2025). At this point, the STEAM approach, which is interdisciplinary, practice-based and emphasizes the active participation of the child, shows a natural harmony with preschool education (Ajimoti, 2022). This understanding is examined under the concept of "early STEAM education" and aims to provide interdisciplinary experiences at an early age (Kao et al., 2025). In this period, play-based activities play a central role in children's learning (Chen & Wang, 2025). It is reported that activities such as a garment folding robot, catapult, seed algorithm or crane construction carried out with a project-based learning approach improve social and cognitive skills, as well as encourage critical and analytical thinking (Capraro & Slough, 2013; Kanaki & Kalogiannakis, 2022). However, the availability of classrooms with technical equipment for STEM applications stands out as an important element in terms of the effectiveness of applications (Hunter-Doniger, 2021).

STEM children use scientific and mathematical knowledge in technology and engineering applications to identify, question, and propose solutions to problems (Bagiati & Evangelou, 2016; Bybee, 2010). As a matter of fact, research in kindergartens reveals that the integration of STEM principles leads to meaningful advances in children's knowledge, skills, and collaboration abilities (Wang et al., 2025). Teachers guide this process with a constructivist approach, but may encounter various obstacles such as lack of resources, lack of pedagogical strategies, and family-school collaboration (Huang et al., 2022). In addition, it has been determined that STEAM applications based on block games positively affect children's creativity, imagination and performance and improve their spatial thinking skills (Kao et al., 2025). STEAM applications do not require complex materials; Everyday objects such as stones, branches, seeds, or cardboard can also support the learning process (Bevan, 2017; Kao et al., 2025). However, it is stated that there are both opportunities and challenges in transforming teachers' pedagogical strategies (Leung, 2023). For example, in studies where story-based STEM design activities were examined in the context of kindergarten, differences were observed in children's emotional, attention and behavioral participation levels. Teachers, on the other hand, use various methods in the preparation, implementation, and evaluation stages to support their learning processes (Zhou & Yang, 2024a).

Kindergarten Children and Cognitive Skills

Cognitive skills encompass the basic mental functions used in individuals' information acquisition, processing, and meaning-making processes (Pandey, 2025). When considered in the context of STEM/STEAM education, these skills are; it includes a wide range of areas such as problem-solving, critical thinking, creativity, algorithmic thinking, spatial reasoning and scientific process skills. These skills play a critical role in the development of children's capacity to cope with the increasingly complex problems of the 21st century (Turiman et al., 2012; Yalcin, 2022).

Problem-solving skills, which are at the core of STEM education, support children's ability to identify and analyze real-life problems, develop solutions, implement them, and evaluate the results (Akçay Malçok & Ceylan, 2022). Studies have shown that preschool STEM practices create statistically significant improvements in children's problem-solving capacities (Kanaki & Kalogiannakis, 2025). Critical thinking is an important cognitive skill that allows individuals to analyze information in a structured way, distinguish between facts and opinions, make informed decisions, and come up with creative solutions (Trilling & Fadel, 2009; Wu, 2021). This skill begins to develop from an early age and is strengthened when supported by appropriate learning environments (Kanaki & Kalogiannakis, 2025). STEM practices effectively develop critical thinking by encouraging children to ask questions, generate hypotheses, conduct experiments, and reach conclusions with an inquiry-based learning approach (Wang et al., 2025). Sub-dimensions of critical thinking include interpretation, analysis, evaluation, inference, explanation, and self-regulation (Bybee, 2013; Wang et al., 2025).

It includes abilities such as creativity, originality, flexibility, fluency, elaboration, and generating new ideas (Kao et al., 2025; Sangngam, 2021; Somwaeng, 2021). STEM-based activities play an important role in supporting creativity and contribute to the permanent development of these skills from an early age (Stone-MacDonald et al., 2015; Uret & Ceylan, 2021). Research shows that STEM practices in the preschool period have positive effects on creativity and support the sub-dimensions of creativity (Hu et al., 2010; Uret & Ceylan, 2021). In this context, Torrance creative thinking tests (form A and form B) are frequently used as a measurement tool (Uret & Ceylan, 2021). Another skill is; It is algorithmic thinking. This skill is a fundamental part of CT and encompasses processes such as problem decomposition, pattern recognition, abstraction, and algorithm design (Kanaki & Kalogiannakis, 2025; Komis et al., 2021). Early childhood teachers use methods such as question-answer activities, unplugged strategies, algorithm design, and basic code reading to develop this skill (Abanoz & Kalelioğlu, 2025). These activities, which mostly target low-level thinking, also support higher-level cognitive abilities such as programming, analysis, and evaluation over time (Macrides et al., 2022). In addition, the age factor stands out as an important variable in the development of algorithmic and therefore CT (Kanaki & Kalogiannakis, 2025).

Spatial reasoning refers to the ability of individuals to perceive the visual environment, create objects in the mind, and associate these processes with motor skills (Mercan & Kandır, 2024; Newcombe, 2010). This skill is directly related to many fields such as science, mathematics, architecture, and design (Mercan & Kandır, 2024; Newcombe, 2010). CT provides a mental framework based on developing systematic and effective solutions to problems (Çiftçi & Topçu, 2023a; Shute et al., 2017). Considered one of the essential skills of the 21st century, this skill is a universal competence that must be developed from an early age (Kanaki & Kalogiannakis, 2025; Shute et al., 2017; Wing, 2006). This skill is considered to be a science (Arık & Topçu, 2022; Ketelhut et al., 2020; Peel & Friedrichsen, 2018), mathematics (Lavigne et al., 2020), technology (Hacker, 2018), and engineering (Ehsan et al., 2021; Hacker, 2018) disciplines increase the meaningfulness of learning (Çiftçi & Topçu, 2023a).

When the relevant research are examined, it is seen that there are many systematic reviews and reviews that deal with the multifaceted dimensions of STEM/STEAM education related to early childhood. A systematic review by Pandey (2025) addressed how kindergarten teachers integrate STEM toys into children's play processes. This review revealed teachers' perspectives on these toys, while also shedding light on the cognitive and social-emotional consequences of children's STEM-based play experiences. The findings showed that STEM toys made positive contributions to skills such as problem-solving, critical thinking, and verbal communication. Similarly, the systematic review conducted by Rodrigues-Silva and Alsina (2023) discussed the role of STEM/STEAM education in early childhood education in the context of environmental sustainability. In the research, it was emphasized that an Apollonian perspective that supports children to develop virtuous attitudes towards sustainability comes to the fore, but STEM/STEAM skills should be more visibly integrated into the sustainability curriculum.

Studies focusing on the creativity dimension in STEM/STEAM education also draw attention. Systematic reviews by Alexandre et al. (2022) and Aguilera and Ortiz-Revilla (2021) examined the effects of STEM and STEAM interventions on student creativity, revealing that both approaches yielded positive results on creative thinking. However, it has been noted that assumptions that STEAM directly enhances creativity superior to STEM are not fully supported by empirical data (Aguilera & Ortiz-Revilla, 2021; Alexandre et al., 2022; Pandey, 2025). On the other hand, Komis et al. (2021) systematically examined the last 30 years of research and categorized the educational and technological opportunities of smart toys for children aged 3-12 years. In addition to gains such as problem-solving and collaboration, the study revealed that in recent years, the focus has shifted from general skills to STEM and CT. Çetin and Demircan (2020), who discussed the role of robotic programming in early childhood STEM education, emphasized that educational robots contribute to cognitive development by integrating engineering and technology into learning processes.

Among other research on technology integration, augmented reality applications stand out. Ibáñez and Delgado-Kloos (2018) and Rosenzweig and Wigfield (2016) examined the prevalence of AR-powered STEM learning experiences and highlighted the importance of meta-cognitive scaffolding, inquiry-based learning, and blended learning strategies for future work. Similarly, Takeuchi et al. (2020) examined transdisciplinary approaches in STEM education and emphasized the necessity of studies that go beyond interdisciplinary boundaries.

Relevant research shows that algorithmic thinking and makerspace applications also play an important role in children's cognitive development. Ebony and Kalelioglu (2025) found that teachers use question-answer and unplugged activities to improve algorithmic thinking, but these practices often target lower-level skills. Yang et al. (2025) and Zhan et al. (2025), on the other hand, stated in their studies conducted in China that makerspace-based STEM programs support children's mental habits, school maturity and emotional well-being. A study conducted by Mercan and Kandır (2024) in Turkey also revealed that early STEAM education is effective in developing children's visuospatial reasoning skills. These comprehensive findings show that STEM/STEAM education is examined in different dimensions in early childhood. However, the fragmented structure of the existing literature and the findings obtained in different contexts necessitate a more holistic approach to the field. At this point, this study aims to make a unique contribution to the field by analyzing how cognitive skills are shaped in the context of STEM/STEAM in early childhood.

METHODS

Research Design

In this study, the systematic review research model was adopted, which allows the existing studies to be examined systematically and transparently. The systematic review method is a powerful method that aims to identify, analyze, and synthesize studies in a specific research area in a comprehensive, objective, and reproducible manner (Gough et al., 2017; Petticrew & Roberts, 2006). Considering the increasing interest in the impact of STEM/STEAM education on cognitive skill development in early childhood, the systematic review method provides an appropriate framework for the holistic presentation of knowledge in this field.

The research process was carried out in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guideline, which sets out the standard reporting and execution criteria for systematic reviews (Moher et al., 2009; Page et al., 2021; Zhunussova, 2025). This review follows the five-step framework developed by Arksey and O'Malley (2005). These are

(1) identifying initial research questions,

(2) identifying relevant studies,

(3) selecting studies,

(4) tabulating data, and

(5) combining, summarizing, and reporting results.

These stages were used in this review, which examines the effects of STEM/STEAM on the development of cognitive skills in early childhood education.

Identifying Relevant Studies

The universe of the study; *Web of Science* and *Scopus* databases are English-published studies on the effect of STEM/STEAM education on cognitive skill development in early childhood, the full text of which can be accessed. In this context, a total of 36 studies were included.

Data Collection Techniques

Screening strategy and inclusion/exclusion criteria

1. The scanning process in the databases was done on 15.07.2025.
2. The terms "*STEM/STEAM*" AND "*Early childhood*", "*STEM/STEAM*" AND "*Preschool*", "*STEM/STEAM*" AND "*Kindergarten*", "*STEM/STEAM*" AND "*Young children*" were searched in the titles as keywords in the databases. Cognitive research was selected from this study. In addition, since some studies have titles as early STEM/STEAM, a code scan was included as (*TITLE (STEM) AND TITLE (early)) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SUBJAREA,"SOCI"))*.
3. Have a research or review article.
4. As a result of the relevant literature review in the research; Author, year of publication, publication title, database, subject, journal information and abstract information were determined in accordance with the purpose and these data were withdrawn.

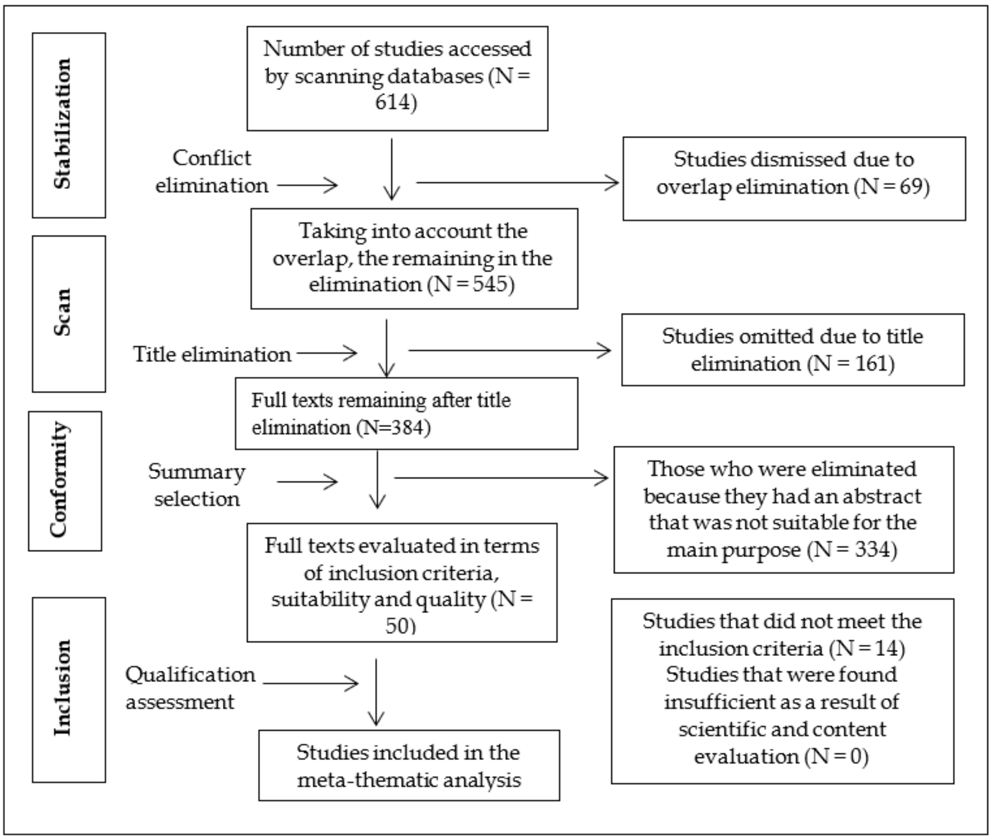

Figure 1. Flow diagram of the studies included in the analysis (Source: Authors' own elaboration)

5. In the research, each research was numbered by using the *Academic Publication Evaluation Form* prepared in this context, and apart from those specified; It *was withdrawn from the research for the reporting process* as a bibliography in APA 7 style.

Reasons for not including the research study in the context of the case study:

1. Not available in relevant databases.
2. The full text is not accessible.
3. Lack of focus on STEM/STEAM education in early childhood.
4. Not published in English.

It can be specified in the form of.

As can be seen in the PRISMA diagram in **Figure 1**, all research were scanned from the relevant databases within the scope of keywords in order to determine the research suitable for the analysis. Among the studies whose full texts can be accessed, 614 studies were included in the study pool. Of the studies examined, 69 studies that were in duplication/overlap of the same research in both keywords and databases were excluded from the scope. In the second stage, the remaining 545 studies were examined in depth, and 161 of these studies were removed from the pool due to unrelated topics, 334 because they were not suitable for the main purpose, and 14 because they did not meet the inclusion criteria. The remaining 36 studies were transferred to the *Mendeley Program* for evaluation as they were fit for purpose.

Analysis of Data

In the study, document analysis was used in the analysis of the data. Docs; journals, biographies and autobiographies, technical documents, field notes, diaries, official records, papers, reports or statistics, primary or secondary sources, historical events or chronologies, projects, plans, letters, photographs, books, articles (Cohen et al., 2007). It is known that documents are important sources of information about the relevant field and researchers generally work on these written documents in qualitative research (Wallwn and Fraenkel, 2013).

In the study, document analysis was carried out in two stages. These;

1. In the study group*, it was obtained from Web of Science* and *Scopus* bases and transferred to the computer environment in pdf format. In the study, *Mendeley Reference Manager and Excell* programs were used in the collection, classification and presentation of the data.
2. In the second stage, the analysis of the studies transferred to the computer environment sorted according to the code number was carried out through the Academic Publication Evaluation Form developed within the scope of the research. In qualitative research, descriptive analysis techniques were used in the data analysis process. The first method applied in this process is frequency analysis, which focuses on examining

the frequency of occurrence of message elements. In this type of analysis, countable units are determined and analysis indicators are expressed over frequency values. Frequency analysis provides a simple and understandable view of recording units and allows them to measure the intensity of repetition of certain elements while examining the material. Thanks to this method, the importance of the analyzed items and their density in the context can be evaluated, and the items can be classified according to their frequency (Köhler & Stemmler, 1997). In addition, categorical analysis involves first dividing a particular message into smaller units and then grouping these units into categories according to predetermined criteria (Tavşancıl & Aslan, 2001). This approach allows the data to be systematically organized and the analyzed content to be examined under meaningful categories.

Validity and Reliability of the Research

In qualitative research, validity refers to the researcher's observation of the phenomenon as accurately and impartially as possible. Validity also requires the researcher to explain how they collected and analyzed the data and to report the findings in detail (Creswell, 2014; Patton, 2015).

In qualitative studies, validity is generally handled with the dimensions of internal and external validity. Internal validity is related to the adequacy of the research process to accurately reflect the reality of the phenomenon under study. Therefore, it is of great importance for the researcher to be consistent in the data collection, analysis and interpretation processes (Maxwell, 2013). In this study, detailed explanations were given in the findings section in order to ensure internal validity, the data related to the research subject were presented objectively, and then the interpretations were started. Similarities and differences were clearly demonstrated by considering the criteria of consistency, internal homogeneity and external heterogeneity between the data (Patton, 2015). External validity is related to the generalizability of research findings. If the results of the research can be replicated in similar settings and conditions, external validity is considered to be achieved (Creswell, 2014). In this study, the publications obtained from the databases are explained in detail and the raw data are presented in the appendices. In addition, the data are detailed in a way that allows comparison with different databases (Patton, 2015).

In this context, the analysis of the data was carried out by two experts and the reliability level of the study was calculated within the framework proposed by Miles and Huberman (1994): *Reliability = Consensus/(consensus + disagreement)*.

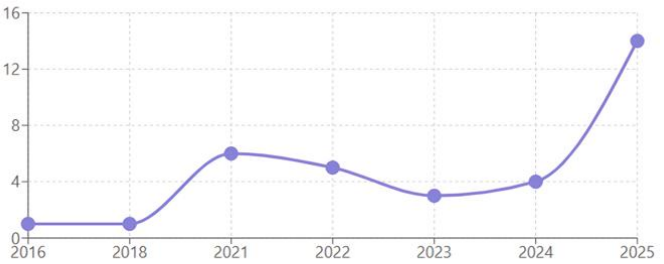

Figure 2. Change of research over the years (Source: Authors' own elaboration)

In the calculation made according to the reliability formula, the reliability of the research was found to be 85%. Reliability calculations above 70% show that the research is reliable. According to the results obtained, it can be said that the research is reliable.

RESULTS

Descriptive Results

In this part of the study, descriptive information about the effects of STEM/STEAM education on cognitive skill development in the preschool period (especially kindergarten age), changes according to years, changes according to research types and changes according to the journals in which they are published are included.

When the data in **Figure 2** are examined, it is understood that the research on STEM/STEAM education in early childhood has been increasing over the years. The first studies were conducted in a limited number in 2016 (n = 1) and 2018 (n = 1), and a significant increase in the number of studies (n = 6) was observed in 2021. This was followed by studies conducted in 2022 (n = 5) and studies in 2023 (n = 3). By 2024, the number of studies increased slightly (n = 4), and in 2025, it reached its highest level (n = 15) and exhibited a remarkable intensity. This distribution reveals that academic interest in the effects of STEM/STEAM education on cognitive skill development in the preschool period is increasing.

When the distribution according to research types is examined (**Figure 3**), the majority of the studies are articles (n = 32). In addition, there are a limited number of master's theses (n = 2) and conference papers (n = 2). This shows that the subject is mainly addressed through scientific articles published in peer-reviewed journals, while theses and papers offer a more limited contribution.

When the data in **Table 1** are examined, it is seen that the journal with the most publications *is Education Sciences* and a significant part of the total publications (n = 6; 16.67%). This was followed by *Thinking Skills and Creativity* (n = 4; 11.11%) and *European Early Childhood Education Research Journal* (n = 3; 8.33%). In addition, there are two publications (*5.56%) in journals such as* International Journal of Technology and Design

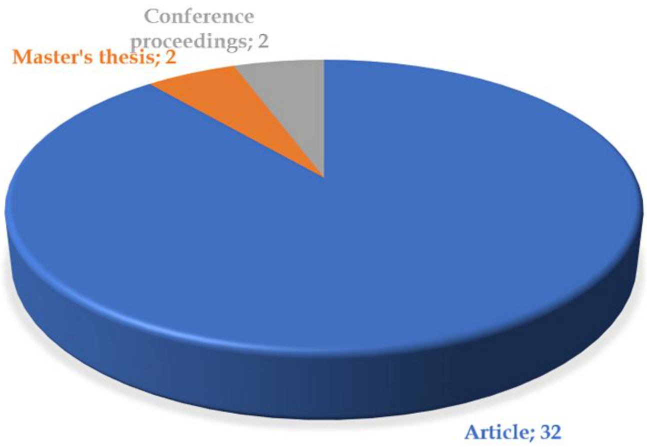

Figure 3. Change of research by types (Source: Authors' own elaboration)

Education, Early Child Development and Care, *and Journal of Physics: Conference Series*. Other journals, master's theses and conference papers (2.78%) are represented.

Findings for the First Sub-Research Question

The findings on which cognitive skills of kindergarten children are based on STEM/STEAM education research are presented in **Table 2**.

Looking at **Table 2**, it is seen that STEM/STEAM education in early childhood contributes to the development of children's different cognitive skills. Studies deal with cognitive skills under various categories: basic, high-level, related to language and communication, creativity and flexibility, social and emotional, and specific cognitive skills. In the category of basic cognitive skills, there are a limited number of studies on attention and perception (1 each), which shows that there is relatively little research in this area. On the other hand, problem-solving (n = 10) was the most common skill within the scope of high-level cognitive skills, followed by critical thinking (n = 5), logical reasoning (n = 4), decision making (2) and analytical thinking (n = 2). This situation reveals that STEM/STEAM education is especially associated with problem-solving-oriented approaches.

Among the cognitive skills related to language and communication, comprehension (n = 8) was the most examined dimension, while language development (n = 3) and symbolic thinking (n = 2) were handled in a more limited way. In the category of creativity and flexibility, creativity stands out as the most intensively studied area (10), while cognitive flexibility (n = 2) and metacognition (n = 1) are relatively understudied. Social and emotional cognitive skills include social problem-solving (n = 3) and emotional regulation (n = 2), which shows that STEM/STEAM practices support not only cognitive but also social-emotional aspects. Within the scope of special cognitive skills, algorithmic thinking (n = 4), CT (n = 4), design thinking (n = 3) and spatial reasoning (n = 2) were studied. These findings show that STEM/STEAM education supports children's cognitive development in a multidimensional way in line with contemporary educational approaches.

Table 1. Findings for the journals in which the related research is published

Journal name	Number of publications (N)	Percentage (%)
Education Sciences	6	16.67
Thinking Skills and Creativity	4	11.11
European Early Childhood Education Research Journal	3	8.33
International Journal of Technology and Design Education	2	5.56
Early Child Development and Care	2	5.56
Journal of Physics: Conference Series	2	5.56
Environmental Education Research	1	2.78
Mills College (master's thesis)	1	2.78
Kwara State University (master's thesis)	1	2.78
International Journal of Knowledge Management	1	2.78
Research in Science and Technological Education	1	2.78
International Journal of Early Years Education	1	2.78
Cultural Studies of Science Education	1	2.78
CTE-STEM Conference Proceedings	1	2.78
Art Education	1	2.78
Australian Educational Researcher	1	2.78
Asia-Pacific Journal of Research in Early Childhood Education	1	2.78
International Journal of Child-Computer Interaction	1	2.78
Nutrients	1	2.78
Knowledge Management & E-Learning-An International Journal	1	2.78
Science and Education	1	2.78
Early Childhood Education Journal	1	2.78
Education 3-13	1	2.78

Table 2. Research distribution by cognitive skills

Cognitive skills category	Cognitive skill	n	Research
Basic cognitive skills	Attention	1	Tsuchiya and Gyobu (2025)
	Perception	1	Liang et al. (2025)
High-level cognitive skills	Problem-solving	10	Akcay Malçok and Ceylan (2022), Basaran and Bay (2023), Çiftçi and Topçu (2023a), Ebony and Kalelioglu (2025), Huang et al. (2022), Maslin et al. (2025), Nguyen and Vu (2025), Sangngam (2021), Yalcin (2024), & Zhan et al. (2025)
	Critical thinking	5	Basaran and Bay (2023), Çiftçi and Topçu (2023b), Nguyen and Vu (2025), Yalcin (2024), & Zhang et al. (2024)
	Logical reasoning	4	Çiftçi and Topçu (2023b), Ebony and Kalelioglu (2025), Huang et al. (2022), & Mercan and Kandır (2024)
	Decision-making	2	Basaran and Bay (2023) & Zhang et al. (2024)
	Analytical thinking	2	Ebony and Kalelioglu (2025) & Zhang et al. (2024)
Cognitive skills associated with language and communication	Comprehension	8	Akcay Malçok and Ceylan (2022), Chen and Wang (2025), Ebony and Kalelioglu (2025), Huang et al. (2022), Liang et al. (2025), Stage et al. (2025), Yalcin (2024), & Zhang et al. (2024),
	Language development	3	Ajimoti (2022), Fridberg and Redfors (2024), Stage et al. (2025)
	Symbolic thinking	2	Çiftçi and Topçu (2023ab?) & Liang et al. (2025)
Creativity and flexibility	Creativity	10	Hunter-Doniger (2021), Kao et al. (2025), Maslin et al. (2025), Nguyen and Vu (2025), Sangngam (2021), Somwaeng (2021), Tsuchiya and Gyobu (2025), Uret and Ceylan (2021), & Yalcin (2021, 2024),
	Cognitive flexibility	2	Yang et al. (2025) & Damjanovic and Branson (2025)
	Metacognition	1	Çiftçi and Topçu (2023a)
Social and emotional cognitive skills	Social problem-solving	3	Basaran and Bay (2023), Garner et al. (2018), & Zhan et al. (2025)
	Emotional regulation	2	Garner et al. (2018) & Yang et al. (2025)
Specific cognitive skills	Algorithmic thinking	4	Çiftçi and Topçu (2023a, 2023b), Ebony and Kalelioglu (2025), & Kanaki and Kalogiannakis (2022)
	CT	4	Çiftçi and Topçu (2023a, 2023b), Huang et al. (2022), & Yang et al. (2025)
	Design thinking	3	Yalcin (2021, 2024) & Zhou and Yang (2025a)
	Spatial reasoning	2	Mercan and Kandır (2024) & Liang et al. (2025)

Results for the Second Sub-Research Question

The findings regarding the question of how the effects of STEM/STEAM activities applied in early childhood on cognitive development differ according to the pedagogical approaches applied are presented in **Table 3**.

The data presented in **Table 3** comprehensively reveal the effects of different pedagogical approaches on

Table 3. Pedagogical approaches and their effects on cognitive development

Pedagogical approach	Areas of cognitive development	Impact status	Highlights	Supporting research	Age group
Play-based learning	Creative thinking, problem-solving, cognitive flexibility, spatial reasoning	Positive-intermediate	The STEAM-based block game dramatically boosts creative imagination; strong connection between play, autonomy and creativity; simultaneous development of social and cognitive skills	Basaran and Bay (2023), Hunter-Doniger (2021), Kao et al. (2025), & MacDonald et al. (2022)	3-6 years old
Inquiry-based learning	Critical thinking, scientific process skills, hypothesis-making, analytical thinking	Positive-high level	Hybrid modality practices strengthen critical thinking; age-related development in algorithmic thinking skills; inquiry-based robotics applications increase vocabulary	Chen and Wang (2025), Fridberg and Redfors (2024), Kanaki and Kalogiannakis (2022), & Zhang et al. (2024)	4-6 years old
Hands-on learning	Manipulative skills, spatial intelligence, motor-cognitive coordination, conceptual comprehension	Positive-intermediate	When tangible technologies and low-tech tools are used together, STEM participation increases; makerspace environments develop STEM thinking skills; physical manipulation embodies abstract concepts	Damjanovic and Branson (2025), Liang et al. (2025), & Yang et al. (2025)	3-6 years old

Table 3 (Continued). Pedagogical approaches and their effects on cognitive development

Pedagogical approach	Areas of cognitive development	Impact status	Highlights	Supporting research	Age group
Project-based learning	Problem-solving, social cognitive skills, planning and organization, creative thinking	Positive-intermediate	Project-based STEAM activities provide simultaneous development of social and cognitive skills; long-term projects build deeper conceptual understanding; collaborative project work strengthens social problem-solving skills	Basaran and Bay (2023), Zhan et al. (2025), & Zhou and Yang (2025a, 2025b)	4-6 years old
Design thinking	Creative problem-solving, 21st century skills, innovation skills, empathy and user orientation	Positive-limited level	STEM activities prepared with the design thinking model significantly increase creativity and problem-solving skills; holistic development of 21st century skills; prototyping processes increase cognitive flexibility	Yalcin (2021, 2024)	5-6 years old
5E-EDP model	Creativity, systematic thinking, engineering design process, conceptual transfer	Positive-limited level	The 5E-EDP model is effective in developing the creativity of children aged 5-6; the systematic approach supports conceptual understanding; engineering design process structures problem-solving skills	Nguyen and Vu (2025)	5-6 years old
Social-constructivist approach	Social cognitive development, language development, collaborative learning, cultural understanding	Positive-intermediate	Social interaction supports cognitive development; the positive impact of cultural contexts on STEM learning; peer learning increases conceptual understanding	Aguilar (2016) & Garner et al. (2018)	4-6 years old
Unplugged CT	Algorithmic thinking, CT, logical reasoning, problem decomposition	Positive-high level	CT activities without technology significantly improve their skills; teaching abstract concepts with concrete experiences is effective; increases self-efficacy beliefs	Çiftçi and Topçu (2023a, 2023b)	3-6 years old
Robotics assisted learning	Programming thinking, STEM competencies, technical language development, systematic thinking	Positive-high level	Educational robotics is effective in developing STEM competencies; robotic-assisted teaching increases the use of words by teachers and children; learnability of programming concepts at an early age	Fridberg and Redfors (2024) & Trapero-Gonzalez et al. (2025)	4-6 years old
Story-based STEM approach	Narrative thinking, contextual learning, creative problem-solving, language-STEM integration	Positive-high level	Story-based STEM design challenges increase children's participation; the narrative structure facilitates the understanding of STEM concepts; strong link between language skills and STEM learning	Stage et al. (2025) & Zhou and Yang (2025a, 2025b)	3-6 years old

cognitive development areas in early childhood. In general, approaches such as game-based, inquiry-based, applied and project-based learning contribute positively to skills such as cognitive flexibility, problem-solving and creative thinking. Game-based learning especially supports creativity and social-cognitive development, while inquiry-based learning develops critical thinking and scientific process skills at a high level. Hands-on learning strengthens conceptual understanding with concrete materials, while project-based learning develops social problem-solving and planning skills through long-term and collaborative processes.

More structured approaches, such as design thinking and the 5E-EDP model, support skills such as creative problem-solving, the engineering design process, and conceptual transfer, albeit to a limited extent. It is seen that the social-constructivist approach contributes to social-cognitive development, especially through peer interaction and cultural context. In addition, technological and non-technological information-based methods such as unplugged CT and robotic-assisted learning are found to be highly effective on algorithmic thinking, programming concepts and STEM competencies. In addition, the story-based STEM approach increases children's participation, establishes a strong link between language skills and STEM learning, and contributes to making abstract concepts more understandable. When these data are evaluated holistically, it is understood that different pedagogical approaches at an early age have positive effects on cognitive development in different dimensions, especially in the fields of creativity, problem-solving and critical thinking.

Results on the Third Sub-Research Question

The findings on the contribution of the classroom environment and learning materials to the development of cognitive skills are presented in **Table 4**. The findings reveal the effects of different types of materials and learning environments used in early childhood on cognitive development in a multidimensional way. First of all, technology-based tools stand out in the development of digital literacy and algorithmic thinking skills. Visual programming environments contribute to children's ability to comprehend abstract concepts in a more concrete way, and interactive technologies increase their motivation to learn. In particular, age-appropriate

Table 4. Types of materials and their effects on cognitive development

Material/media type	Targeted cognitive skills	Specific contributions	Supporting research	Age appropriateness	Application recommendations
Technology-based tools	Digital literacy, programming thinking, technological problem-solving, systematic thinking	Visual programming environments support algorithmic thinking; digital tools embody abstract concepts; interactive technologies increase motivation	Çiftçi and Topçu (2023a), Fridberg and Redfors (2024), & Trapero-Gonzalez et al. (2025),	4-6 years old	Age-appropriate programming languages, visual coding tools, interactive digital platforms
Robotic vehicles	Programming logic, cause-effect relationship, spatial reasoning, problem-solving	Robotic tools facilitate the transition between concrete and abstract concepts; scripts improve algorithmic thinking; error-correction loops support learning	Fridberg and Redfors (2024), Kanaki and Kalogiannakis (2022), & Trapero-Gonzalez et al. (2025)	4-6 years old	Programmable robots, block-based coding, step-by-step scripts
Manipulative materials	Hand-eye coordination, spatial intelligence, geometric thinking, fine motor skills	Physical manipulation embodies abstract mathematical concepts; hands-on experiences deepen conceptual understanding; motor skills support cognitive development	Damjanovic and Branson (2025), Liang et al. (2025), & Yang et al. (2025)	3-6 years old	Geometric shapes, counting materials, construction blocks, puzzles
Block & build games	Spatial reasoning, creative thinking, planning skills, 3D visualization	STEAM-based block games boost creative imagination; 3D structures improve spatial skills; building processes support engineering thinking	Mercan and Kandır (2024) & Kao et al. (2025)	3-6 years old	Lego type blocks, magnetic blocks, wooden building sets, 3D puzzles
Game-based learning tools	Social cognitive skills, collaboration, problem-solving, creativity	Game environments provide natural motivation to learn; social games improve collaboration skills; role-playing increases empathy and perspective-taking skills	Basaran and Bay (2023), Hunter-Doniger (2021), & MacDonald et al. (2022),	3-6 years old	Role-play materials, cooperative plays, dramatization tools
Makerspace environments	Creativity, innovation, practical problem-solving, design thinking	Makerspace environments develop STEM thinking skills; construction-creation processes teach the design cycle; the use of multiple materials increases creativity	Damjanovic and Branson (2025) & Yang et al. (2025),	4-6 years old	Miscellaneous building materials, simple tools, recycling materials, art supplies
Hybrid technology-low technology combination	Integrated thinking, technology adaptation, multimodal learning, flexibility	The combined use of tangible technologies and low-tech tools increases STEM participation; multi-sensory experiences reinforce learning; providing a technology-real-life connection	Damjanovic and Branson (2025) & Zhang et al. (2024)	3-6 years old	Digital-physical hybrid games, augmented reality tools, interactive projection systems

Table 4 (Continued). Types of materials and their effects on cognitive development

Material/media type	Targeted cognitive skills	Specific contributions	Supporting research	Age appropriateness	Application recommendations
Symbol and visualization tools	Symbolic thinking, spatial representation, abstraction skills, mathematical thinking	Technology-enabled symbol creation spatializes STEM learning; visual representations make abstract concepts accessible; children's creation of their own symbols increases conceptual understanding	Chen and Wang (2025) & Liang et al. (2025)	4-6 years old	Digital drawing tools, symbol cards, graphic organizers, concept maps
Nature and outdoor materials	Exploration, observation skills, scientific inquiry, environmental awareness	Natural materials provide authentic learning experiences; outdoor exploration boosts scientific curiosity; environmental context supports STEM learning	Ebony and Yabas (2025) & Maslin et al. (2025)	3-6 years old	Natural objects, exploration tools, observation record forms, nature collections
Story and narrative tools	Language-STEM integration, contextual learning, narrative thinking, creative expression	Story-based STEM activities increase children's participation; the narrative structure makes STEM concepts understandable; books and digital stories support STEM learning	Stage et al. (2025) & Zhou and Yang (2025a, 2025b)	3-6 years old	STEM-themed books, digital story tools, interactive e-books, story cards

programming languages and visual coding tools allow children to develop systematic thinking skills at an early stage. Robotic tools, on the other hand, are effective in comprehending programming logic and cause-effect relationships. Children's step-by-step work with scripts supports algorithmic thinking processes and increases the permanence of learning through error-correction loops. The use of programmable robots with block-based coding contributes to the development of both cognitive and problem-solving skills.

Manipulative materials support the development of hand-eye coordination, spatial intelligence, and motor skills, which form the basis of cognitive development at an early age. Through physical manipulation, children are able to embody abstract mathematical concepts and their conceptual understanding processes are deepened. Counting materials, geometric shapes, puzzles and blocks stand out as indispensable tools of early childhood education in this respect. STEAM-based building games allow children to experience engineering thinking; İt supports planning and problem-solving skills. In particular, lego-type or magnetic blocks allow abstract concepts to be internalized with structural designs. Game-based learning tools stimulate natural motivation to learn, developing collaboration and empathy skills through social games. Role plays and dramatization activities contribute to children's experience of different perspectives and thus to the strengthening of their social cognitive development. Makerspace environments play an important role in the development of creativity and innovation skills. A variety of building materials and simple tools are used in these environments, allowing children to experience the design cycle and develop practical problem-solving skills. In this process, the use of multiple materials supports children's flexible thinking and innovative solutions.

Hybrid technology-low technology combinations improve children's integrated thinking and multimodal learning skills based on the combined use of both digital and physical tools. Symbols and visualization tools enable children to make sense of abstract concepts more easily. Digital drawing tools, concept maps and symbol cards strengthen spatial representation skills, as well as support conceptual understanding by the processes by which children produce their own symbols. Nature and outdoor materials are decisive in the development of scientific inquiry, observation and environmental awareness skills at an early age. Story and narrative tools strengthen language-STEM integration and support children's contextual learning experiences. STEM-themed books, digital stories and story cards increase children's creative expression skills and conceptual understanding. The narrative structure makes STEM concepts more understandable, making this method an effective tool for early childhood education.

Results on the Fourth Sub-Research Question

How do family involvement and parental support shape the effects of STEM/STEAM practices on the cognitive development of kindergarten children? The findings are presented in **Table 5**. According to the findings, the types of family involvement include

Table 5. Types of family involvement and their cognitive development effects

Type of family involvement	Targeted cognitive skills	Specific effects	Supporting research	Forms of application	Age appropriateness
Home environment STEM support	Numeracy skills, problem-solving, mathematical thinking, scientific curiosity	It has been observed that parents' STEM professions enrich the home numeracy environment and increase children's numerical competencies; STEM conversations at home nurture scientific curiosity.	Ebony and Yabas (2025) & Mues et al. (2021)	STEM games at home, math apps for everyday life, asking scientific questions	3-6 years old
School-family cooperation projects	Social learning, practice transfer, conceptual reinforcement, motivation	Learning deepens when STEM experiences are maintained between school and home; family participation increases children's motivation to participate in STEM activities.	Basaran and Bay (2023) & Garner et al. (2018)	Homework, family STEM night, collaborative projects	4-6 years old
Parent STEM literacy	Academic achievement, STEM attitude development, learning transfer, language development	Parents' STEM knowledge level directly affects children's academic success; families with high STEM literacy offer richer learning experiences to their children.	Huang et al. (2022) & Mues et al. (2021)	Parent training programs, STEM resource sharing, guidance materials	3-6 years old
Emotional support and encouragement	Self-confidence, risk-taking, creativity, problem-solving motivation	Familial encouragement and support enable children to take risks and experiment with creative solutions in STEM fields; social-emotional support improves cognitive performance.	Garner et al. (2018) & Hunter-Doniger (2021)	Positive reinforcement, celebrations of success, permission to make mistakes	3-6 years old
Home-school material continuity	Concept transfer, reinforcement, variety of applications, deep learning	The presence of similar STEM materials at home facilitates concept transfer. Encountering the same concepts in different contexts reinforces learning.	Damjanovic and Branson (2025) & Yang et al. (2025)	Home STEM kit, common materials, guided activities	3-6 years old
Digital platform family engagement	Digital literacy, online learning, use of technology, hybrid learning	During the COVID period, family support played a critical role in hybrid STEM education models; family guidance on digital platforms increases the quality of children's learning.	Maslin et al. (2025) & Zhang et al. (2024)	Online STEM activities, digital family games, remote learning support	4-6 years old
Cultural context and values	Cultural learning, value systems, social cognitive development, identity formation	The integration of cultural values with STEM learning supports children's identity development. Different cultural perspectives broaden the understanding of STEM.	Aguilar (2016) & Garner et al. (2018)	Cultural STEM stories, family traditions, multilingual STEM	3-6 years old
Social-economic support strategies	Equal access, resource use, social justice, equal opportunity	Support programs for families from different social-economic levels ensure equality in STEM access; resource-sharing programs ensure that all children benefit.	Damjanovic and Branson (2025) & Trapero-Gonzalez et al. (2025)	Resource library, free programs, community support	3-6 years old

different approaches and forms of practice that support cognitive development in early childhood. STEM support provided in the home environment increases children's numerical competencies, problem-solving skills and scientific curiosity; parents' knowledge and experience in STEM fields appear to enrich children's mathematical and scientific thinking processes (Ebony & Yabas, 2025; Mues et al., 2021).

School-family collaboration projects increase the depth of learning and strengthen children's motivation by ensuring the continuity of STEM experiences between home and school (Başaran & Bay, 2023; Garner et al., 2018). Parents' STEM literacy plays a decisive role in shaping children's academic achievement and attitudes towards STEM fields; families with high levels of STEM knowledge provide richer learning experiences to their children (Huang et al., 2022; Mues et al., 2021). Emotional support and encouragement increase children's self-confidence, risk-taking tendencies, and creative capacities, while social-emotional support positively affects cognitive performance (Garner et al., 2018; Hunter-Doniger, 2021).

Home-school material continuity enables concept transfer and reinforcement of learning through the availability of similar STEM materials both at home and in the school environment (Damjanovic & Branson, 2025; Yang et al., 2025). Family participation on digital platforms increases children's digital literacy and learning quality, especially in hybrid learning models; family guidance supports the effectiveness of online learning processes (Maslin et al., 2025; Zhang et al., 2024). Cultural context and values support children's identity formation and social cognitive development through STEM learning; the incorporation of different cultural perspectives into learning broadens conceptual understanding (Aguilar, 2016; Garner et al., 2018). Social-economic support strategies, on the other hand, ensure equality in all children's access to STEM; Resource and support programs for families from different social-economic levels contribute to the realization of equal opportunities (Damjanovic & Branson, 2025; Trapero-Gonzalez et al., 2025).

Different forms of family involvement play a decisive role in the development of children's cognitive skills at an early age; It has positive effects in areas such as mathematical and scientific thinking, problem-solving, creativity and academic motivation. In this context, home-child, school-child and digital environment collaborations are considered as part of a holistic approach that supports cognitive development.

DISCUSSION

The findings of this systematic review study provide a comprehensive perspective on the effects of STEM/STEAM education on cognitive skill development in early childhood. The analysis of 36 studies examined in the study reveals that STEM/STEAM practices in early childhood support children's cognitive development in a multidimensional way. These findings show that STEM education at an early age can have positive effects on a wide spectrum of children's basic cognitive skills to higher-order thinking skills. In particular, the fact that problem-solving skills are the most discussed cognitive skill in research coincides with the nature of STEM/STEAM education and reflects the basic philosophy of educational approaches in this field. This shows that it is possible for children to develop systematic thinking and solution-oriented approaches from an early age.

An examination of the distribution of publications by year reveals that academic interest in STEM/STEAM education in early childhood has increased dramatically, especially in recent years. The fact that the number of studies carried out in 2025 has reached 15 indicates how central this field has become in current educational research (Abanoz & Kalelioglu, 2025; Damjanovic & Branson, 2025). This increase is due to a growing awareness of the acquisition of 21st century skills and a better understanding of the critical importance of early childhood for cognitive development. Especially in the post-pandemic period, the integration of digital technologies into education and the spread of hybrid learning models have contributed to the acceleration of research in this field (Zhang et al., 2024). This trend highlights the importance of early childhood educators and researchers examining STEM/STEAM approaches more systematically.

The diversity of cognitive skills addressed in the research shows how holistic STEM/STEAM education supports children's development. The fact that problem-solving skills are discussed in 10 studies reveals that this skill is one of the main outputs of STEM/STEAM education (Akcay Malcok & Ceylan, 2022; Yalcin, 2021). The frequent examination of critical thinking and logical reasoning skills that follow shows that children can develop higher-order thinking skills at an early age. The existence of 10 studies in the field of creativity indicates that STEM/STEAM education supports not only analytical thinking, but also creative and flexible thinking skills (Uret & Ceylan, 2021; Yalcin, 2024). This situation reveals that STEM/STEAM education can develop both convergent and divergent thinking skills of children together.

Findings on the effects of pedagogical approaches on cognitive development show that different teaching strategies make unique contributions to the development of children's cognitive skills. The fact that the game-based learning approach supports creativity and social-cognitive development reveals that it can successfully blend the natural learning tendencies of early childhood with STEM/STEAM education (Hunter-Doniger, 2021). The fact that inquiry-based learning develops critical thinking and scientific process skills shows that children can acquire habits of thinking in accordance with scientific methodology from an early age. This situation, when evaluated within the framework of Vygotsky's social-cultural learning theory, supports that with appropriate guidance and support, children can make significant progress in their potential developmental levels. The fact that project-based learning improves social problem-solving and planning skills reveals that STEM/STEAM education supports social skills as well as individual cognitive development.

Findings on the contribution of technology-based tools to cognitive development show how important technology plays in the learning processes of children in the digital age. The fact that visual programming environments contribute to children's ability to comprehend abstract concepts in a more concrete way reveals that CT skills can be developed at an early age (Çiftçi & Topçu, 2023a). The fact that robotic tools are effective in comprehending the logic of programming and cause-effect relationships shows that they support children's algorithmic thinking processes (Kanaki & Kalogiannakis, 2022). These findings indicate that technology is not only a tool but also offers an environment that structures thinking processes. However, the fact that the use of technology should be supported by age-appropriate programming languages and visual coding tools emphasizes the importance of considering the developmental characteristics of children. In this context, it is understood that it is critical to blend technology integration with pedagogical approaches in a balanced way.

The contribution of manipulative materials to cognitive development shows how compatible STEM/STEAM approaches are with the basic principles of early childhood education. The ability of children to embody abstract mathematical concepts through physical manipulation reflects the characteristics of the period of concrete operations emphasized in Piaget's theory of cognitive development. Counting materials, geometric shapes and blocks are important in terms of deepening the conceptual comprehension processes, the development of children's hand-eye coordination, spatial intelligence and motor skills, and cognitive development. Block and build games develop creativity and 3D visualization skills, allowing children to experience engineering thinking while also supporting planning and problem-solving skills (Kao et al., 2025). This situation reveals how effective the nature of STEM/STEAM education, which combines theoretical knowledge with practical application, can be in early childhood.

The contributions of makerspace environments and hybrid technology-low technology combinations to cognitive development reflect the effects of 21st century learning environments on children. The use of a variety of construction materials in these environments allows children to experience the design cycle and develop practical problem-solving skills (Yang et al., 2025). The fact that the use of multiple materials supports children's flexible thinking and innovative solutions skills shows that creativity and innovation skills can be developed at an early age. It is important for hybrid technology combinations to develop children's integrated thinking and multimodal learning skills in order to respond to the needs of children with different learning styles. These finding highlights how diverse and flexible learning environments are critical in unlocking children's cognitive potential.

The contribution of symbols and visualization tools to cognitive development reveals the importance of visual representations in the development of children's abstract thinking skills. The fact that digital drawing tools, concept maps, and symbol cards strengthen spatial representation skills suggests that the processes by which children produce their own symbols support conceptual understanding (Liang et al., 2025). This points to how visuospatial intelligence, which is emphasized in Howard Gardner's theory of multiple intelligences, can be developed through STEM/STEAM education. The development of symbolic thinking is the foundation for children's understanding of more advanced concepts in mathematics and science, while visualization skills are also critical in engineering and design processes. These findings suggest that children's symbolic representation skills should be systematically supported in early childhood.

The contributions of nature and outdoor materials to cognitive development emphasize the importance of integrating environmental education approaches and STEM/STEAM education. The fact that such materials are decisive in the development of scientific inquiry, observation and environmental awareness skills shows the strong effect of children's exploratory activities carried out in natural environments on cognitive development. While nature-based STEM activities stimulate children's sense of curiosity, they also allow them to lay the foundations of scientific methodology (Ebony & Yabas, 2025). This approach reveals that children have more meaningful and lasting learning experiences when faced with real-world problems. Developing environmental awareness at an early age is also critical for the integration of sustainable development goals into education systems.

The role of story and narrative tools in STEM/STEAM education illustrates how language skills can be integrated into science, technology, engineering, and mathematics learning. The fact that these tools increase children's creative expression skills and conceptual understanding reveals how effective narrative pedagogy can be in STEM fields (Zhou & Yang, 2025a, 2025b). The use of STEM-themed books, digital stories, and story cards helps children make abstract concepts more understandable, while also supporting their language development. This finding highlights the importance of the "A" (arts) of the STEAM approach and shows how powerful art and literature can be for STEM learning. The fact that narrative structure supports contextual learning plays a critical role in helping children transfer the information they have learned to real-life situations.

The role of family involvement in the effectiveness of STEM/STEAM education emphasizes that educational processes are not limited to school walls and the importance of family support in children's cognitive development. It is critical for the continuity of learning that STEM support provided in the home environment increases children's numerical competencies, problem-solving skills, and scientific curiosity (Mues et al., 2021). The fact that school-family cooperation projects increase the depth of learning and strengthen the motivation of children emphasizes the importance of the educational ecology approach. The impact of parents' STEM literacy on children's academic achievement reveals the necessity of parent education programs. The fact that emotional support and encouragement increase children's self-confidence and creative capacities shows that social-emotional factors should also be considered in STEM/STEAM education.

The fact that family participation on digital platforms increases children's digital literacy and learning quality emphasizes the importance of hybrid education models in the post-pandemic era (Zhang et al., 2024). The fact that cultural context and values support children's STEM learning and identity formation shows how multicultural educational approaches can be integrated with STEM/STEAM education (Garner et al., 2018). The role of social-economic support strategies in ensuring equal opportunities reveals that the issue of justice in education should also be addressed in the context of STEM/STEAM applications. When these findings are evaluated holistically, they show that the effectiveness of STEM/STEAM education can be increased through school, family and community cooperation, and that this approach requires a multidimensional strategy to support children's cognitive development.

The results of the research reveal that the positive effects of STEM/STEAM education on cognitive skill development in early childhood are multidimensional and comprehensive. As the research findings show, with appropriate pedagogical approaches, a variety of learning materials and strong family support, significant improvements can be made in children's problem-solving, creativity, critical thinking and many other cognitive skills. These findings highlight the importance of early childhood educators applying STEM/STEAM approaches more systematically and consciously. At the same time, it is critical that research in this area continues to increase and that similar studies are carried out in different cultural contexts for a better understanding of the global effectiveness of STEM/STEAM education. Future research may provide findings that will further enrich the body of knowledge in this field, especially through longitudinal studies and comparative analyses.

CONCLUSION AND RECOMMENDATIONS

A review of research on the effects of STEM/STEAM education on cognitive development in early childhood shows that academic interest in this field has increased significantly in recent years. After the first studies were carried out in limited numbers in 2016 and 2018, a significant increase in the number of studies has been observed since 2021 and it has been determined that the studies have reached the highest level by 2025. When the research types are examined, it is seen that the subject is mainly handled through articles published in peer-reviewed journals, while master's theses and conference papers make limited contributions. Among the journals published, *Education Sciences*, *Thinking Skills and Creativity*, and *European Early Childhood Education Research Journal* stand out.

Research shows that STEM/STEAM education contributes to different dimensions of children's cognitive skills. Although basic cognitive skills have been studied at a limited level, problem-solving, critical thinking and logical reasoning stand out in high-level cognitive skills. Among the skills related to language and communication, comprehension was determined as the most examined dimension, while skills such as creativity and cognitive flexibility were supported by different pedagogical approaches. Within the scope of social-emotional and special cognitive skills, STEM/STEAM applications make positive contributions in areas such as social problem-solving, emotional regulation, algorithmic and CT, design thinking and spatial reasoning.

When pedagogical approaches are examined, it is seen that game-based, inquiry-based, applied and project-based learning methods especially support problem-solving, creativity and critical thinking skills. Structured approaches such as design thinking and the 5E-EDP model strengthen creative problem-solving and conceptual transfer, albeit at a limited level; technology-supported learning methods develop algorithmic thinking, programming and STEM competencies. Story-based STEM activities, on the other hand, increase participation by integrating children's language and conceptual learning processes.

The effects of the materials and learning environments used on cognitive development are also multidimensional. While technology-based tools support digital literacy and systematic thinking skills, robotic applications are effective in problem-solving and understanding the cause-effect relationship. Manipulative materials and building games support the development of hand-eye coordination, spatial intelligence, creativity, and engineering thinking. Hybrid learning environments, symbol and visualization tools, and digital platforms deepen children's conceptual understanding and encourage multimodal learning.

Family involvement stands out as a critical factor that strengthens the effects of STEM/STEAM applications. Support provided in the home environment, school-family cooperation projects and guidance through digital platforms positively affect children's mathematical and scientific thinking, problem-solving, creativity and academic motivation levels. Social-economic support, cultural context and values enrich children's learning experiences and contribute to ensuring equal opportunities. In general, STEM/STEAM activities implemented in early childhood support cognitive, social and emotional development in a multidimensional way through different pedagogical approaches and various materials. In particular, the achievements in the fields of problem-solving, creativity and critical thinking reveal the strong contributions of early STEM/STEAM education to cognitive development. These findings highlight the importance and applicability of holistic and integrated STEM/STEAM practices in early childhood education.

In line with the findings revealing the contributions of STEM/STEAM education to cognitive development in early childhood, some suggestions are made to researchers, practitioners and education policy makers. Considering that the number of studies on early STEM/STEAM education is increasing, researchers should conduct more comprehensive research, especially in the areas of basic cognitive skills and metacognition; should carry out multidimensional studies that integrate the dimensions of language, communication and social-emotional development. In addition, measuring the effects of different pedagogical approaches through comparative and long-term monitoring studies will contribute to the determination of effective strategies in early childhood education.

For practitioners, teachers and early childhood educators should use a balance of play-based, inquiry-based, hands-on and project-based learning methods; integrate technological tools, manipulative materials, and hybrid learning environments to support children's cognitive, social, and emotional development. Teachers should primarily adopt active learning strategies in classroom practices in order to develop children's problem-solving, creativity and critical thinking skills. In addition, collaborating with families to provide sustainable STEM experiences at home and using digital platforms effectively will increase the depth of learning processes.

For education policy makers, it is recommended to develop national and local policies and programs that support STEM/STEAM education in early childhood. Improve the quality of pedagogical practices by investing in education policies, teacher training and professional development programs; consider social-economic and cultural differences to ensure that all children have access to STEM learning opportunities. Policies that encourage school-family collaboration projects will allow for the provision of consistent STEM experiences in the home and school environment. In addition, resource allocations and hybrid learning platforms that support digital and physical material infrastructure should be among the strategic investments that will increase the effectiveness of STEM/STEAM practices in early childhood. In this context, it is of great importance to ensure a strong coordination between the knowledge production of researchers, the pedagogical practices of practitioners and the strategic planning of education policy makers in order for STEM/STEAM practices in early childhood education to be effective, inclusive and sustainable.

Limitations

The research has some limitations. Firstly, only Web of Science and Scopus databases were used in the research, and studies that could be obtained from other academic databases (ERIC, PsycINFO, Google Scholar, etc.) were excluded. This may have overlooked some important studies on the impact of STEM/STEAM education on cognitive skill development in early childhood. In addition, only studies published in English were included in the scope of the research, and studies published in other languages were excluded from the evaluation. This limitation may have led to overlooking the findings of studies, especially those conducted in different cultural contexts, and reduced the generalizability of the results. The limited combination of keywords used in the research may have led to the fact that studies on the subject but using different terminology could not be identified. In addition, although the reliability level of the analysis process performed by two experts in the systematic review process was calculated as 85%, subjective evaluations have the potential to affect the research results. Finally, the number of 36 studies included may be limited to making sweeping generalizations about the effects of STEM/STEAM education on cognitive skills development in early childhood. It is important to consider these limitations in the interpretation of research findings and in the development of recommendations for future studies.

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Ethical statement: The authors stated that the study is a systematic review and does not involve direct research with human participants; therefore, ethical committee approval was not required. The review was conducted in accordance with the PRISMA guidelines and adhered to established ethical standards in academic research. All sources were properly cited, and data were analyzed with integrity and transparency.

AI statement: The authors stated that no generative AI or AI-based tools were used in the writing, analysis, or preparation of this manuscript.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX

Table A1. Articles included in the systematic review

Abanoz, T., & Kalelioglu, F. (2025). Unleashing the potential: Illuminating pedagogical strategies employed by early childhood educators in stem education for cultivating algorithmic thinking skills in young learners. *European Early Childhood Education Research Journal, 33*(1), 138-158. https://doi.org/10.1080/1350293X.2024.2339274
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