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M. Zainul Arifin*, Cyndana Kartika Putri, and Laila Mubarakah

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Strategies and concepts for developing number sense in early childhood: A systematic review

M. Zainul Arifin[1], Cyndana Kartika Putri[2], and Laila Mubarakah[3]

[1]*Mathematics Education, Universitas Lambung Mangkurat, Banjarmasin, Indonesia*
[2]*Mathematics Education, Universitas Palangka Raya, Palangka Raya, Indonesia*
[3]*Early Childhood Education, Universitas Lambung Mangkurat, Banjarmasin, Indonesia*

ABSTRACT

Number sense is a foundational skill in early mathematics learning; however, comprehensive reviews of effective strategies and key concepts in early childhood education remain limited. This study systematically reviews approaches to developing number sense, identifies the most frequently studied mathematical concepts, and analyzes factors influencing their effectiveness. Using a Systematic Literature Review (SLR) methodology, twelve peer-reviewed journal articles were selected from the Scopus database based on the following inclusion criteria: publications between 2016 and 2025, written in English, indexed in Scopus, within the field of education, and available as open access. Studies published in conference proceedings or books, those outside the specified timeframe, written in other languages, or behind paywalls were excluded. The review followed PRISMA guidelines to ensure rigor and transparency. The findings indicate that game-based learning, multiple representations, digital tools, exploratory activities, and problem-solving tasks are frequently employed to strengthen number sense. The key mathematical concepts emphasized include cardinality, number representation, basic operations, quantity structure, and early reasoning. Their effectiveness depends on teacher competence, student engagement, instructional strategies, and the learning environment. This study contributes to a deeper understanding of early numeracy development and highlights the importance of child-centered, adaptive, and experience-based approaches. The results provide valuable insights for educators, curriculum developers, and policymakers seeking to improve mathematics instruction at the early childhood level..

KEYWORDS

Early childhood mathematics; early learners; mathematical concept development; number sense; systematic literature review

CORRESPONDING AUTHOR

M. Zainul Arifin ✉ mzainul.arifin@ulm.ac.id 🖃 Mathematics Education, Universitas Lambung Mangkurat, Banjarmasin, Indonesia

INTRODUCTION

Number sense refers to the cognitive ability to comprehend numerical concepts and to manipulate numbers flexibly across various mathematical contexts. It encompasses an understanding of numerical values and the relationships among numbers, as well as skills in calculation, estimation, and adaptive numerical reasoning. Several studies (e.g., Farida, 2014; Hidayah & Sholihah, 2023) indicate that students with higher mathematical ability demonstrate stronger number sense skills. However, many Indonesian students continue to struggle with basic numeracy, highlighting the need to strengthen number sense education from an early age (Nurjanah & Hakim, 2019). Traditional teaching methods often rely on abstract concepts and worksheets, which may be ineffective for young learners (Noreen & Rana, 2019). To address

this issue, multisensory approaches using concrete materials have shown promise in improving number sense in early childhood education (Fitri & Kholid, 2020). These approaches engage multiple learning modalities, making it easier for children to grasp numerical concepts through play.

Despite these efforts, Farida (2014) found that many students still struggle to develop a comprehensive understanding of numbers and operations, particularly in mastering place value, basic arithmetic operations, and number relationships. Such findings suggest that difficulties in number sense are not only widespread but also persist across different grade levels. More recent studies support this view. For instance, Kusmaryono et al. (2020) reported that Indonesian elementary students often experience misconceptions when comparing numerical magnitudes, while Birgin & Peker (2024) emphasized that limited number sense skills negatively affect students' problem-solving performance. These persistent challenges indicate that number sense remains a fundamental foundation in mathematics learning, as highlighted by Torbeyns et al. (2015), who stressed its critical role in supporting the development of arithmetic fluency and higher-order mathematical thinking.

Number sense development begins in infancy and continues through the early school years, with interventions such as number board games showing promising results. However, a study by Novitasari et al. (2024) found that number sense abilities remain low among prospective elementary school teachers, particularly in their understanding of numbers and operations. Similar findings have been reported among Indonesian elementary students, who struggle with number concepts, especially fractions and decimals (Lewis et al., 2020). The importance of number sense also extends to higher education, where a significant positive correlation has been found between number sense and mathematical problem-solving ability among mathematics education students (Clarke & Beck, 2021). These findings underscore the need for greater emphasis on number sense development across all educational levels to enhance overall mathematical performance and problem-solving skills.

Research on numeracy skill development has gained significant attention in recent years, with various studies exploring different instructional approaches and interventions. A comprehensive literature review by Sood & Mackey (2014) categorizes interventions by instructional type and discusses outcomes related to student characteristics and assessment methods.

Several systematic literature reviews have examined early childhood education, focusing on areas such as environmental literacy, cognitive development, and social-emotional

development (Ardoin & Bowers, 2020; Blewitt et al., 2018). However, these studies do not specifically address how fundamental mathematical concepts, such as number sense, are developed, defined, and implemented in early childhood learning contexts. This gap highlights the need for a focused systematic review on number sense in early education.

This study aims to address this gap by conducting a systematic review based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, focusing on original peer-reviewed research articles published within the last ten years. The use of these guidelines ensures methodological rigor and enhances the reliability of the findings. Accordingly, this study contributes not only to the academic literature through knowledge synthesis but also offers practical implications for educators and policymakers in designing more effective and sustainable early childhood mathematics programs.

The research questions (RQs) guiding this study are as follows:

RQ1: What approaches, strategies, and learning methods are used to develop number sense in young learners?

RQ2: What basic mathematical concepts are most frequently examined in the development of number sense in young children?

RQ3: What factors influence the effectiveness of number sense learning in early childhood and early elementary education?

METHODS

The present study employed a Systematic Literature Review (SLR) as its primary research method. An SLR is a rigorous approach to collecting and synthesizing relevant data on a specific topic based on predefined eligibility criteria (Mengist et al., 2020). The review process was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which reflects advances in methods for identifying, selecting, appraising, and synthesizing studies. The use of an SLR is consistent with the objectives of this study, as it provides a structured and transparent means of synthesizing existing research (Page et al., 2021). This approach enables the consolidation of current knowledge on number sense while identifying gaps and directions for future research. Figure 1 presents the PRISMA flow diagram used in this study, illustrating the progression of articles through each stage of the review process.

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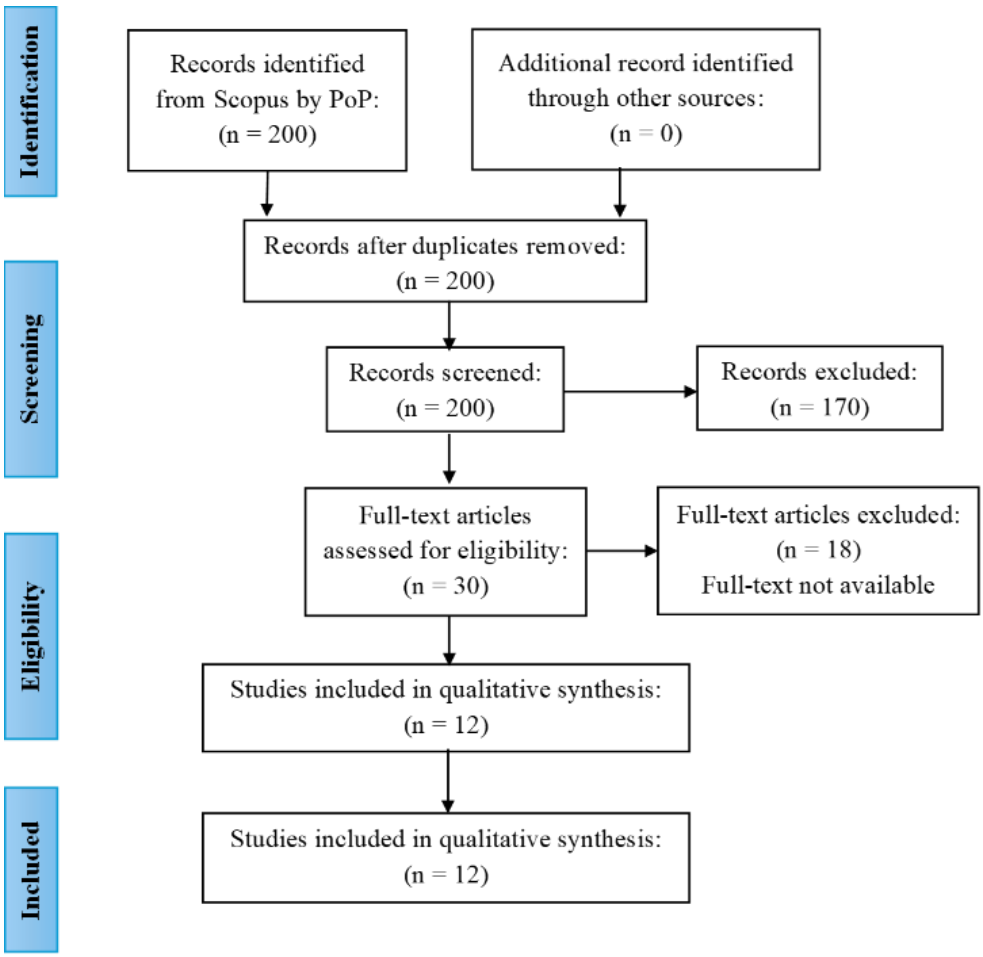

Figure 1. PRISMA Flowchart

Identification

A literature search was conducted using Harzing's Publish or Perish (PoP) software, with the Scopus database as the primary source. Scopus was selected because it is one of the most credible academic indexing databases, offering broad coverage and comprehensive analytical features. Although other databases, such as Web of Science, ERIC, and ProQuest, also provide valuable coverage, Scopus was considered the most appropriate to ensure both the breadth and relevance of the retrieved literature (Arifin et al., 2025).

It is important to note that the search process was conducted using PoP software, which has a technical limitation of retrieving a maximum of 200 articles per query. To address this limitation, the search strategy was refined and expanded by optimizing keyword combinations, systematically applying inclusion and exclusion criteria, and manually verifying the relevance of the retrieved articles to ensure that the final dataset adequately represented the scope of the study.

Moreover, due to the lack of direct access to a Scopus institutional account, the search

could not be conducted directly through the Scopus platform. To ensure comprehensive retrieval of relevant literature, the search strategy incorporated the following keywords: ("number sense" OR "mathematical concept" OR "mathematics education" OR "mathematical thinking" OR "mathematics learning") AND ("early learners" OR "early childhood education" OR "preschool").

Although the use of PoP imposes a limitation on the maximum number of retrieved articles, this constraint was mitigated by applying predefined inclusion and exclusion criteria, cross-checking article relevance against the research objectives, and ensuring that the final selection represented a comprehensive and relevant body of literature for further analysis.

Screening

At this stage, a set of inclusion and exclusion criteria was applied. Articles in the form of systematic reviews, books, book chapters, and conference proceedings were excluded. Additionally, only journal articles written in English and published within the last ten years were considered to ensure contextual relevance and currency of information. Following the screening process, 170 articles were eliminated for failing to meet these criteria, leaving 30 articles for the subsequent stage of review.

Eligibility

All articles that passed the initial screening were examined in greater depth, considering aspects such as title, abstract, methodology, results, and discussion. Articles that did not explicitly address the development of number sense in young children or were not available in full text were excluded. At this stage, 18 articles were deemed ineligible, leaving 12 articles that met the inclusion criteria and aligned with the research objectives.

Inclusion and Exclusion Criteria

To ensure the quality and relevance of the findings, the final selection was based on predetermined criteria, including year of publication, document type, language, and topic relevance. These criteria were designed to identify articles that directly supported the research focus. As shown in Table 1, 12 relevant articles were selected and were available in full text for further analysis.

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Table 1. Criteria for Inclusion and Exclusion

Criteria	Inclusion	Exclusion
Title and abstract of the article	Appropriate title aligned with research objectives	Irrelevant title or not aligned with study requirements
Type of publication	Journal publications	Publications in proceedings or books
Year of publication	Published between 2016 and 2025	Published outside the specified range
Language	English language	Other languages
Area of study	Field of education	Other than education
Indexing database	Indexed in Scopus	Not indexed in Scopus
Accessibility	Full-text and open-access articles	Articles requiring payment or only available as previews

RESULT AND DISCUSSION

Table 2. Eligible Articles for Analysis

No	Author	Title
1	Parks (2020)	"Centering Children in Mathematics Education Classroom Research"
2	Sprenger & Benz (2020)	"Children's perception of structures when determining cardinality of sets—results of an eye-tracking study with 5-year-old children"
3	Dillon et al. (2017)	"Cognitive science in the field: A preschool intervention durably enhances intuitive but not formal mathematics"
4	Soboleva et al. (2020)	"Didactic Potential of Using Mobile Technologies in the Development of Mathematical Thinking"
5	Reuter (2023)	"Explorative mathematical argumentation: a theoretical framework for identifying and analysing argumentation processes in early mathematics learning"
6	Aragón-Mendizábal et al. (2017)	"Improving number sense in kindergarten children with low achievement in mathematics"
7	Gulz et al. (2020)	"Preschoolers' Understanding of a Teachable Agent-Based Game in Early Mathematics as Reflected in their Gaze Behaviors – an Experimental Study"
8	Parviainen et al. (2023)	"Teaching Early Mathematical Skills to 3- to 7-Year-Old Children — Differences Related to Mathematical Skill Category, Children's Age Group and Teachers' Characteristics"
9	Marín-Díaz et al. (2020)	"The Possibilities of Gamifying the Mathematical Curriculum in the Early Childhood Education Stage"
10	Bakar et al. (2020)	"Use of Multiple Representations in Understanding Addition: The Case of Pre-school Children"
11	Watts et al. (2018)	"What Is the Long-Run Impact of Learning Mathematics During Preschool?"
12	Palmér & van Bommel (2020)	"Young students posing problem-solving tasks: what does posing a similar task imply to students?"

Based on the PRISMA framework, the initial search retrieved 200 articles from Scopus using Publish or Perish. Applying the inclusion and exclusion criteria at the screening stage eliminated 170 articles. Studies were excluded if they were not written in English, not published in peer-reviewed journals, focused on subjects outside mathematics education, did not explicitly address number sense, or involved populations other than young children. After this screening, 30 articles remained for full-text review. A detailed evaluation excluded an additional 18 articles, either because they were not relevant to the research focus or because the full text was inaccessible. For the latter, efforts were made to obtain access by checking alternative databases, searching institutional repositories, and contacting authors via email; however, the complete texts could not be retrieved, and the articles were therefore excluded. The final 12

articles met all criteria and formed the basis for synthesizing strategies and concepts for developing number sense in young children. These articles, which constitute the primary sources for subsequent analysis, are summarized in detail in Table 2.

RQ 1. Approaches, strategies, and learning methods are used to develop number sense in young learners

A review of 12 articles reveals that various approaches, strategies, and learning methods are employed to develop number sense in young children. One of the most prominent strategies is game-based learning and intuitive activities. Mathematical games in preschool have been shown to significantly improve children's intuitive understanding of numbers and spatial concepts, although their effects on formal learning remain limited (Dillon et al., 2017). The use of interactive digital technologies, such as the *Playing with Numbers-2* software (Aragón-Mendizábal et al., 2017) and the *Magical Garden* game based on teachable agents (Gulz et al., 2020), has also been shown to increase children's engagement and early numeracy competencies.

Another important approach is the use of multiple representations in mathematics learning. Case studies involving preschool-aged children indicate that they can use and translate various forms of representation (visual, symbolic, and verbal) to understand addition, particularly when supported by guided interactions (Bakar et al., 2020). Additionally, children's ability to recognize visual structures is a crucial element in building number understanding. Eye-tracking studies show that five-year-old children can recognize patterns (e.g., the four-dot arrangement on a die) and use them to determine quantities, although not all children can yet link visual perception with the concept of cardinality (Sprenger & Benz, 2020).

The development of mathematical argumentation from an early age also receives attention. The concept of Explorative Mathematical Argumentation (EMA) highlights how children construct reasoning and arguments through exploration and interaction, which is important for strengthening conceptual understanding (Reuter, 2023). The integration of digital technology and gamification further supports enjoyable and adaptive mathematics learning. Research on mobile technology use (Soboleva et al., 2020) and gamified mathematics curriculum design (Marín-Díaz et al., 2020) shows that these approaches can reinforce conceptual relationships while increasing children’s motivation to learn.

Teachers’ characteristics and pedagogical awareness significantly influence the development of number sense. Studies indicate that teachers often focus more on numerical skills than on spatial or reasoning skills, particularly among children aged 5–7, and that this

emphasis is strongly influenced by teachers' professional training and pedagogical awareness (Parviainen et al., 2023). A child-centered learning approach is also crucial, as children in the same learning environment may experience different levels of pedagogical access; educators must consider individual needs and interaction styles (Parks, 2020). Finally, problem-posing activities, where students create their own math problems, have been shown to improve conceptual understanding and reflective thinking about the structure of mathematical problems (Palmér & van Bommel, 2020).

RQ2. Basic mathematical concepts are most frequently examined in the development of number sense in young children

Several basic mathematical concepts consistently emerge as central in the development of number sense in early childhood. These concepts include cardinality, number representation, addition and other basic operations, quantity structure, mathematical reasoning and argumentation, and spatial thinking.

Cardinality is one of the most frequently mentioned concepts. Sprenger & Benz (2020) demonstrate that five-year-old children can recognize visual patterns in sets of objects and use them to determine quantity, highlighting meaningful counting as a foundational aspect of number sense development. Number representation, both symbolic and non-symbolic, is also a key focus. Dillon et al. (2017) , found that learning activities involving symbol-free mathematical games significantly improve children's intuitive understanding of numbers. Similarly, Bakar et al. (2020) show that children can use multiple forms of representation—such as pictures, concrete objects, and symbols—and switch between them to understand addition.

Basic operations, particularly addition, are frequently studied in the context of strengthening number sense. Bakar et al. (2020) explicitly discusses how preschool-aged children comprehend addition through problem-solving activities that involve multiple representations. Quantity structure is another important aspect that supports number understanding. Sprenger & Benz (2020) emphasize the role of visual structures, such as patterns on dice, which children recognize to aid counting and grouping.

Mathematical reasoning and argumentation are emerging areas of study in early childhood. Reuter (2023) introduces the Explorative Mathematical Argumentation (EMA) framework, which illustrates how children can begin constructing simple mathematical arguments as part of their knowledge building. Finally, although less prominent than numerical concepts, spatial thinking is also highlighted in some studies. Parviainen et al. (2023) note that

spatial skills are taught less frequently than numerical skills but still play an important role in overall mathematical understanding.

RQ3. Factors influence the effectiveness of number sense learning in early childhood education and early elementary school

The effectiveness of number sense learning in early childhood is influenced by several interrelated factors, which can be classified into four main groups: teacher characteristics, learning strategies and media, student characteristics, and learning environment conditions.

First, teacher characteristics—such as pedagogical awareness, teaching experience, and participation in professional training—have a significant impact. (Parviainen et al., 2023) report that the frequency and quality of teaching basic mathematical skills vary depending on teachers' pedagogical awareness, which is shaped by professional development and experience. Teachers with greater pedagogical awareness tend to teach numerical skills relevant to number sense more frequently and consistently.

Second, learning strategies and the media used play a critical role. The use of math games (Dillon et al., 2017), educational software such as *Playing with Numbers-2* (Aragón-Mendizábal et al., 2017), and agent-based learning games like *Magical Garden* (Gulz et al., 2020) has been shown to enhance children's understanding of number concepts. Digital media and interactive technologies enable personalized and adaptive learning, supporting the internalization of mathematical concepts.

Third, children's characteristics—including readiness to learn, interaction styles, and engagement—are also key determinants. Parks (2020) shows that children with similar backgrounds and learning environments may experience different learning outcomes due to their level of engagement and how they access pedagogical support from teachers. Similarly, Sprenger & Benz (2020) highlight that not all children who recognize visual patterns can automatically connect them to the concept of cardinality.

Fourth, a supportive learning environment, including the integration of technology and an atmosphere that encourages exploration, greatly influences learning effectiveness. Soboleva et al. (2020) and (Pakpahan & Saragih, 2022) emphasize the role of mobile technology and gamification in creating an engaging and relevant learning environment for children. In addition, the duration and intensity of interventions contribute to long-term learning outcomes, as demonstrated by Dillon et al. (2017).

To provide a clear overview of how each reviewed article contributes to the research questions, Table 3 summarizes the alignment between each study and the three research

questions. This summary highlights thematic trends, recurring focuses, and potential gaps in the literature.

Table 3. Coverage of Research Questions across the Reviewed Articles

No.	Author	RQ1	RQ2	RQ3
1	Parks (2020)	Child-centered approach	N/A	Individual interactions influence effectiveness
2	Sprenger & Benz (2020)	Visual exploration	Cardinality & quantity structure	Children's ability to connect perception and understanding
3	Dillon et al. (2017)	Intuitive game-based learning	Non-symbolic & symbolic numbers	Duration of intervention influences outcomes
4	Soboleva et al. (2020)	Mobile and digital technology	N/A	Use of technology and digital environments supports learning
5	Reuter (2023)	Exploratory mathematical	Reasoning & argumentation	N/A
6	Aragón-Mendizábal et al. (2017)	Educational intervention software	Basic numerical abilities	Digital learning media supports concept development
7	Gulz et al. (2020)	Game-based learning	Reinforcement of representation	Children's information processing is enhanced through media interaction
8	Parviainen et al. (2023)	Teacher practice surveys & skill categories	Numerical, spatial, reasoning	Teachers' characteristics and pedagogical awareness influence outcomes
9	Marín-Díaz et al. (2020)	Gamification in learning	N/A	Teachers' perceptions inform potential future instructional methods
10	Bakar et al. (2020)	Multiple representations	Concept of addition	Scaffolding and interaction facilitate understanding
11	Watts et al. (2018)	Long-term impact analysis of interventions	Early numeracy learning	Early interventions impact long-term achievement
12	Palmér & van Bommel (2020)	Problem posing	Understanding of problem structure	Children's reflection on the learning process strengthens conceptual understanding

This study aims to systematically review the approaches, strategies, and learning methods used to develop number sense in young children, as well as to identify the most frequently studied basic mathematical concepts and analyze the factors influencing learning effectiveness. A review of 12 articles revealed interconnected findings that enhance our understanding of how number sense develops through various educational approaches at the preschool and early elementary levels.

One key finding is the variety of learning strategies employed in number sense development, including game-based approaches, multiple representations, technology-based interventions, exploratory learning, and problem-posing activities. This aligns with Piaget's

theory of cognitive development, which emphasizes that young children learn most effectively through concrete manipulation in meaningful contexts (Pakpahan & Saragih, 2022). Game-based approaches reported in several studies show that engaging children in enjoyable, age-appropriate activities promotes conceptual understanding of numbers (Oktavianingsih & Fahuzan, 2018). Similarly, the use of educational software and mobile applications reflects Vygotsky's social constructivist theory, particularly regarding scaffolding and guided interaction in learning environments (Haake et al., 2015; Mishra, 2023).

The review also identified the basic mathematical concepts most frequently studied in number sense development, including cardinality, number representation, addition, and quantity structure. Cardinality—the ability to determine the number of objects in a set—was a focus of several studies, especially those using visual structures and eye-tracking techniques (Schöner & Benz, 2018). Number representation, both symbolic and non-symbolic, allows children to link concrete objects with numerical symbols, supporting deeper conceptual understanding (Li et al., 2018). Addition, as a fundamental operation, is often taught through manipulative activities or visual media (Palupi, 2021).

The effectiveness of number sense learning is influenced by several critical factors. Teacher characteristics, such as pedagogical awareness and participation in professional training, play a significant role in determining the quality and frequency of instruction in basic mathematical skills (Parviainen et al., 2024). This is consistent with Cohrssen & Tayler (2016), who emphasize the importance of teacher training for meaningful early mathematics learning. Children's characteristics—such as readiness to learn and how they engage with instructional support—also strongly affect learning outcomes. Even within the same classroom, individual differences in interaction and engagement can lead to varied results (Grimmer, 2018). Even though two children are in the same class with the same teacher and curriculum, their learning outcomes can vary greatly due to differences in individual interaction and engagement (Medina & Sobel, 2020), highlighting the importance of child-centered and flexible approaches. Additionally, a supportive learning environment—including interactive media, adaptive technology, and sufficient intervention duration—enhances the effectiveness of number sense instruction (Kadir et al., 2025).

Compared to previous research, these findings align with the broader literature on early numeracy Sowder (2020), emphasizes that cardinality and number representation form the foundation of number sense. Overall, this study suggests that number sense instruction in early childhood should be designed holistically, taking into account developmentally appropriate

strategies, prioritized mathematical concepts, and factors that support learning success. Implications include the need for enhanced teacher training, the development of adaptive learning materials, and the use of exploratory, experience-based learning designs. These findings further underscore the importance of future research examining the relationship between number sense and other cognitive skills, such as spatial thinking and logic, as well as the long-term effects of early interventions on mathematical achievement across subsequent educational levels.

This study is limited by its inclusion criteria, such as language and publication date, as well as the technical restriction of the Publish or Perish software, which retrieves a maximum of 200 articles per query and may have excluded relevant literature. Future research should expand the scope of sources and further examine the relationship between number sense and other cognitive abilities.

CONCLUSION

According to the findings from a review of twelve publications, the development of children's number sense involves a variety of strategies, emphasizing interactive, exploratory, and learner-centered experiences. The use of digital technology, multiple representations, and game-based activities has been shown to support deeper conceptual understanding. Core mathematical concepts, including cardinality, number representation, addition, and quantity structure, are the primary focus of number sense instruction in early childhood education. Several factors influence learning success, including children’s readiness and engagement, teachers’ pedagogical competence, the learning strategies employed, and the conditions of the learning environment. Individual differences among children, even within the same learning context, highlight the importance of a child-centered and flexible approach. A learning environment that encourages exploration, interaction, and the appropriate use of technology also plays a crucial role in achieving optimal outcomes.

These findings imply that number sense instruction for young children should be designed holistically, considering developmentally appropriate strategies and enhancing teachers’ capacity through continuous professional training. The development of adaptive and contextually relevant teaching materials is also essential to address the diverse learning needs of children.

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