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The role of informal mathematics in the development of mathematical thinking: A systematic review in early childhood

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Abstract
Informal mathematics refers to the mathematical knowledge children construct through everyday experiences before formal schooling. Although recognized as foundation for later mathematical learning, no systematic review has examined how this research is distributed across content domains, age groups, and methods. This study presents a preferred reporting items for systematic reviews and meta-analysis-based systematic review of 48 papers on informal mathematics in early childhood (0-6 years), published between 1982 and 2023 in Web of Science and Scopus. Results show that 83.7% of the papers were published since 2013, mostly using quantitative methods. Most studies focused on numerical thinking in children aged 3 to 6, while algebraic, metric, and stochastic thinking remain underexplored, despite evidence that informal mathematical competence is multidimensional. Only 10.6% focused exclusively on children aged 0 to 3. These gaps constrain the design of comprehensive curricula and interventions, highlighting the need for broader research across domains, younger children, play-based activities, and school-family collaboration.

Keywords: children's mathematical thinking, early childhood education, informal mathematics, systematic review

INTRODUCTION

The study of mathematics development and learning in early childhood has generated radically different points of view (Sarama & Clements, 2009). Until the last decades of the last century, several approaches argued that mathematical knowledge was not mobilized during the first years of life (0-6 years) and, for this reason, research was scarce (Starkey & Klein, 2008). In contrast, contemporary research agendas on human development in general and early childhood mathematics education in particular state that mathematical competence is developed from the first years of life, so there is increasing consensus, attention and dedication to research on mathematics education in early childhood (Alsina, 2020; Baroody et al., 2006; Sarama & Clements, 2009). One of the main reasons for the increase in research on the development of mathematical thinking at early ages is that several studies have found that mathematical development from early childhood is key to holistic development, forms the basis for various competencies, and significantly predicts both later mathematical learning and overall academic performance in the future (e.g., Claessens & Engel, 2013; Watts et al., 2018).

The development of mathematical competence begins with informal experiences – that is, the mathematical notions and processes that children learn through every day, non-school interactions (Baroody, 1987) – in the family environment and through engagement with their surroundings (Starkey & Klein, 2008). These early experiences lay the foundation for the formal mathematics taught later in educational institutions (Baroody, 1987). In this sense, the National Council of Teachers of Mathematics (NCTM, 2000, p. 132) emphasizes that "the most important connection for early mathematics development is between the intuitive, informal mathematics that students have learned through their own experiences and the mathematics they are learning in school".

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Contribution to the literature

- This study provides a first systematic review to highlight the importance of informal mathematics in early childhood. It shows how research in this field is distributed across various types of mathematical thinking, age groups and methods, helping to fill gaps in research related to this topic.
- Methodologically, it applies preferred reporting items for systematic reviews and meta-analysis (PRISMA 2020) to 48 studies spanning 1982-2023 from Web of Science (WoS) and Scopus, using a dual-criterion coding scheme that offers a replicable model for classifying mathematical domains in future reviews.
- The results confirm that research focuses primarily on the numerical thinking in children aged 3 to 6, while algebraic, metric, and stochastic thinking remain underexplored, and reveal that children under 3 are almost entirely absent from the literature, pointing to a clear and relevant direction for future research.

Family interactions and the home learning environment during early childhood have been shown to be significantly associated with children's mathematical outcomes (Lehrl et al., 2020), underscoring the need for greater attention to this area amid current educational challenges, particularly in the field of mathematics. To address low mathematical and academic performance in general, a deeper understanding of the development of informal mathematics in early childhood is needed to provide more and better evidence-based foundations for designing training plans and implementing interventions in homes or schools through educational projects or programs from early childhood onward (Wang et al., 2016).

For this reason, although there are various previous literature reviews that have analyzed trends in early years mathematics education in recent years, this study focuses exclusively on the contribution of informal mathematics to the development of mathematical thinking in early childhood. Consequently, the aim of this research is to conduct a systematic review of papers published by WoS and Scopus journals that have conceptualized and explicitly studied the development and learning of informal mathematics in children between 0 and 6 years of age in the period 1982-2023.

THEORETICAL FRAMEWORK

In this section, we explain what Informal Mathematics means and how several authors (Alsina, 2015; Clements & Sarama, 2009; Geist, 2014) agree that the development of mathematical thinking begins at birth. Then, taking the NCTM standards and the perspectives of the aforementioned authors into account, a parallelism is made between the mathematical contents observed in early childhood, proposing a way to categorize the main modes of mathematical thinking in early childhood development.

Informal Mathematics

Baroody (1987) introduced the term informal mathematics to distinguish the first mathematical notions and processes that are learned in non-school everyday dynamics, which are developed from interactions with physical and social means. The formal mathematics that is identified by the mathematical skills and concepts that a person generally learns in school is usually characterized by more symbolic and written mathematics (Baroody, 1987). Ginsburg and Baroody (2007) distinguish these two forms of learning in order to make sense of the development of mathematical knowledge (Ginsburg et al., 1998).

Baroody (1987) argues that informal mathematics arises from everyday experiences that generate the interest of infants and set the basis for developing their mathematical thinking. Alsina (2015) specifies that these experiences mainly take place in situations of environmental exploration, manipulation, experimentation and play. For example, from a very early age, children play free games where they can explore patterns, shapes and spatial relationships, compare magnitudes, and count objects (Sarama & Clements, 2009).

From this framework, several authors emphasize that the development of mathematical thinking starts at birth: for example, Clements and Sarama (2009) define learning trajectories; Geist (2014) specifies the mathematical concepts that children develop from the age of zero; and Alsina (2015) has documented intuitive and informal mathematics from birth to age 3.

Clements and Sarama (2009, p. 2) mention that children "follow natural developmental progressions in learning math, too, learning mathematical ideas and skills in their own way". Understanding these developmental processes would contribute to designing activities based on them, which in turn constitute developmental pathways that support learning trajectories, which in the words of Clements and Sarama (2009, p. 5) "describe the goals of learning, the thinking and learning processes of children at various levels, and the learning activities in which they might engage". These learning trajectories have been developed for several mathematical content domains, number and quantitative thinking, geometry and spatial thinking, patterns, structure, and algebraic thinking, geometric measurement, and data analysis, each describing a developmental progression through which children advance from informal to increasingly sophisticated mathematical understanding (Clements & Sarama, 2009; Sarama & Clements, 2009).

Geist (2014) uses the term *emergent mathematics* to describe how children construct mathematics from birth and how this continues for the rest of their lives, combining cognitive development and interaction with their different environments, being the interaction with their parents and/or primary caregivers very relevant from birth. Likewise, the author points out that, from a very early age, children begin to build the foundations of future mathematical concepts as they interact mentally, physically and socially with their respective environments and people around them. In his theoretical approach, he highlights the following contents: numbers and operations, geometry and spatial sense; Patterns, reasoning, algebra, measurement, data analysis, probability, and statistics.

Finally, Alsina (2015) notes that children, from birth, develop an intuitive knowledge of mathematics that they use in their informal experiences. According to Fischbein (1987), some of the main characteristics of this knowledge are the following: self-evident, intrinsic certainty, perseverance, coercive or global, among others. In this way, this initial mathematics, which is called intuitive and informal, refers to "the knowledge that children interact from the earliest ages to interpret reality and develop in their daily environment" (Alsina, 2015, p. 26). In this sense, the author indicates that from early childhood one should be constantly and deeply interacting with children's key mathematical ideas, i.e., ideas that link knowledge as a coherent whole for students to see mathematics as a highly connected system of thoughts and concepts across various topics, instead of seeing them as isolated concepts (Toh & Yeo, 2019). The claim that mathematical cognition begins in infancy is now supported by empirical research beyond this theoretical framework. Feigenson et al. (2004) identified two core systems for number representation that are present from early infancy, while longitudinal studies have shown that infants' approximate number sense at 6 to 12 months predicts later mathematical abilities even after controlling for general intelligence (Decarli et al., 2023; Starr et al., 2013). Similarly, spatial processing assessed between 6 and 13 months of age has been found to predict both spatial aptitude and mastery of symbolic-math concepts at age 4, controlling for general cognitive abilities and spatial memory (Lauer & Lourenco, 2016). These findings indicate that domain-specific precursors of mathematical cognition, rather than general cognitive attributes alone, are present from early infancy. However, the extent to which these early competencies constitute separable mathematical constructs (as opposed to domain-general processing) remains an open question for the 0 to 3 age range.

Building on the theoretical and empirical contributions reviewed above (Alsina, 2015, 2022; Clements & Sarama, 2009; Geist, 2014), the present study adopts the five content standards defined by the NCTM (2000), namely number and operations, algebra, geometry, measurement, and data analysis and probability, as an organizing framework for classifying the types of mathematical thinking examined in the reviewed literature. Although these standards span from prekindergarten through grade 12 and their formal expectations begin at the pre-K-2 band (approximately ages 4 and above), the NCTM document itself recognizes that mathematical development begins well before formal schooling, noting that "during the years from birth to age four, much important mathematical development occurs in young children" (NCTM, 2000, p. 73). For children aged 0 to 3, the developmental research reviewed in the preceding subsection provides evidence of domain-specific cognitive precursors (e.g., number sense, spatial processing) that map onto these content categories. Thus, the five NCTM content areas are used here not as curriculum prescriptions for the youngest children, but as a taxonomic structure that allows for a systematic comparison of research coverage across informal mathematical domains and age groups.

Numerical thinking involves understanding counting, numbers and arithmetic. This mode of thinking is considered essential in early mathematical development (Baroody, 2004; Jordan et al., 2009), and it is recommended to emphasize the gradual progression of numerical thinking from early interactions with objects to the acquisition of more advanced numerical concepts during the first years of education. Importantly, research has documented that this progression begins in infancy: preverbal number sense, supported by the approximate number system (Feigenson et al., 2004), has been shown to predict later mathematical abilities from as early as 6 months (Starr et al., 2013) and 12 months of age (Decarli et al., 2023), even after controlling for general intelligence.

Geometric thinking involves recognition and analysis of shapes, spatial visualization, sense of direction and distance in space and logical approach to understand the space in which children live (Clements & Battista, 1992; Newcombe & Huttenlocher, 2000). It encompasses shape identification, composition, and spatial understanding. Evidence suggests that the developmental continuum of this domain begins very early: newborns can process angular relations between line segments and perceive simple forms (Slater et al., 1991), infants as young as 3 to 4 months categorize spatial relations such as above, below, left, and right (Quinn, 2004), and mental rotation ability has been documented by 10 months of age (Frick & Möhring, 2013). Spatial skills at preschool age, including work with blocks, puzzles, and shapes, predict both math and reading achievement at school entry (Verdine et al., 2014).

Algebraic thinking involves beginning to understand quantitative relationships, symbol representation and pattern recognition (Blanton & Kaput, 2011). Exploration, classification, sequencing, as well as pattern recognition and creation prepare children for more advanced algebraic concepts (Mulligan & Mitchelmore, 2009). The description of qualitative and quantitative changes is important for the development of recursive and relational thinking at later stages (Rittle-Johnson et al., 2017). While formal research on algebraic precursors in infancy remains limited, the capacity to detect ordinal relations among numerical values has been documented by 11 months of age (Brannon, 2002), suggesting an early sensitivity to relational structure that may underpin later algebraic reasoning.

The metric thinking prioritizes understanding what a measurable attribute is and being able to use instruments and techniques to measure in different contexts (Clements & Stephan, 2004). In that sense, it is important that the understanding of measurement begins in the early childhood and preschool years. This involves, first, comparing measurements of two objects and recognizing their equality or inequality and, second, practicing measurements. Evidence from infant cognition suggests that precursors of metric understanding emerge early: by 5 months, infants have expectations about the location of objects in continuous space (Newcombe et al., 2005), and by 9 months, they demonstrate cross-dimensional magnitude transfer across number, area, and duration (Lourenco & Longo, 2010), indicating a general magnitude system that may support later measurement concepts.

Stochastic thinking involves the acquisition of skills related to the collection, organization, representation and interpretation of data (Watson, 2006). In this sense, it is important to stimulate children to learn to identify and understand the general characteristics of a data set (English, 2012), to make simple representations with bar graphs using manipulatives and also to distinguish between deterministic and random events, as well as to express the possibility of an event happening on a qualitative scale (Jones et al., 1997). While infant precursors specifically linked to stochastic thinking have not been extensively studied, young children's early ability to detect frequency and regularity in perceptual input may provide a foundation for later data reasoning.

METHOD

In order to discover the current state of research on informal mathematics, the present study is based on a systematic review methodology. This field of research aims "to carry out a review that is rigorous and transparent in each step of the review process, to make it reproducible and updateable" (Zawacki-Richter, 2020, p. vi).

Search Strategy

To do this research, we followed the criteria and procedures of the PRISMA 2020, which aim to facilitate transparent reporting of systematic reviews (Page et al., 2021).

The bibliographic search was conducted in the WoS and Scopus databases, which are internationally recognized for their high-quality publications. These two curated, multidisciplinary citation databases were selected because together they provide broad coverage of peer-reviewed journal literature across disciplines, with complementary disciplinary strengths (Gusenbauer, 2022; Martín-Martín et al., 2018), and are commonly used as core databases in systematic reviews in education (Zawacki-Richter et al., 2020). The search strategy combined two key elements: explicit theoretical aspects of informal mathematics and the target population. In both databases, the first element was operationalized using the following terms connected by OR operators: "informal math*", "informal numeracy", "mathematical informal", "informal number", "informal numerical", "informal count", "informal operation", "informal algebra", "informal pattern*", "informal measurement", "informal shape", "informal geometry", "informal spatial", "informal statistic*", "informal probabili*", and "informal data." The second element targeted the population using: "early childhood", "young children", "child*", "preschool", "infancy", "kinder*", and "toddler." Both elements were combined with the AND operator. In Scopus, the search was applied to title, abstract, and keywords, with results filtered by document type (articles) and language (English and Spanish). In WoS, Topic search was used with no additional filters at the search stage.

Screening Processes

Prior to this stage, the papers were filtered to avoid duplicates; then, the titles and abstracts were reviewed to identify the research papers that appeared to meet the inclusion criteria of the study and to eliminate those that had some elements of the exclusion criteria.

The inclusion criteria were the following:

(1) academic papers in WoS or Scopus to ensure that they are rigorous research papers published in scientific journals that have a demanding review process. These databases provide the broadest multidisciplinary coverage among academic databases, including a substantial proportion of peer-reviewed journals in education and developmental psychology;

(2) publications in English and Spanish, given that the former is usually used as the universal language for scientific research and the latter because it is the language of the authors and highlights publications in Ibero-America;

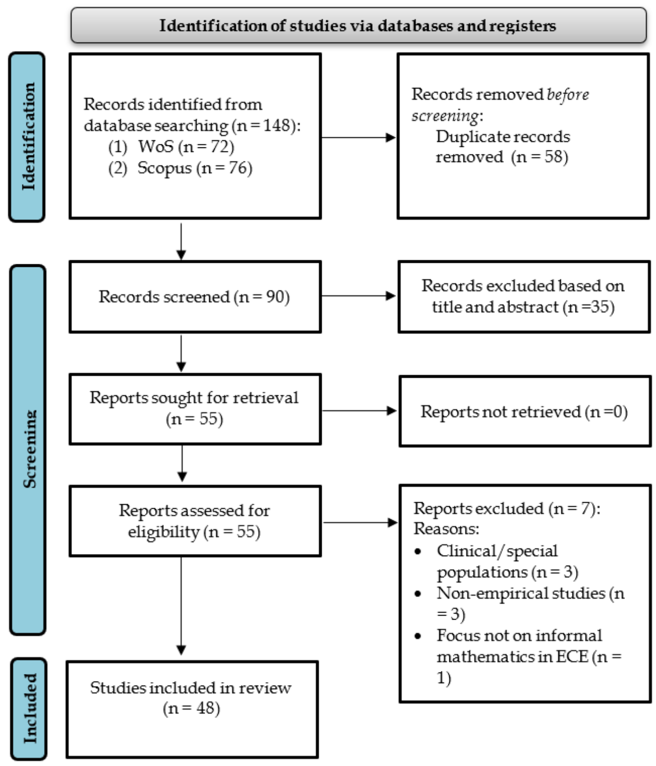

Figure 1. Flow diagram of the paper selection process (adapted from Page et al., 2021)

(3) period of publications, from 1982 – the year of the construct's theoretical emergence – through 2023; and

(4) availability of the whole paper.

The exclusion criteria were the following:

(1) book chapters, complete books, proceedings, editorials, book reviews, notes, among others;

(2) studies that have not been published in English or Spanish;

(3) duplicate papers; and

(4) restricted access to the full text of the paper.

The initial database searches yielded 148 records (72 from WoS and 76 from Scopus). After removing 58 duplicate records identified across both databases, 90 unique records remained for screening. Two reviewers independently screened titles and abstracts against the predefined inclusion and exclusion criteria; discrepancies were resolved through discussion until consensus was reached. During this phase, 35 records were excluded because their disciplinary focus fell outside the scope of the review (e.g., studies primarily situated in engineering, medicine, or geography) or because the participant age range did not correspond to the early childhood population targeted by this study. This resulted in 55 records eligible for full-text assessment; all 55 full texts were successfully retrieved. During full-text review, 7 additional papers were excluded for the following reasons: the study focused on clinical or special populations outside the review's scope, specifically children with spina bifida or intellectual disabilities (n = 3); the study was non-empirical, including theoretical, conceptual, or bibliographic review articles without original empirical data on informal mathematics (n = 3); or the study's primary research focus was not centered on informal mathematics in early childhood education (n = 1). The final sample comprised 48 papers included in the analysis (**Figure 1**).

Analysis

Some categories were defined to allow a more orderly analysis of the selected papers on informal mathematics in early childhood. On the one hand, the categories on the characteristics of the studies are as follows: publications per year; authors' countries; and sample sizes; on the other hand, the categories on the areas of informal mathematics in early childhood education, based on the five types of mathematical thinking described in the theoretical framework: number of mathematical contents per paper; and mathematical thinking addressed, with a more in-depth analysis including author(s), year, topic of study, age, sample and method. This information was recorded in tables, which allowed us to do a descriptive analysis of the data extracted from the screening of the selected papers.

Following the same independent dual-reviewer procedure described above for the screening phase, data were extracted from each paper using a structured coding form. The mathematical thinking domain(s) assigned to each paper were determined based on two criteria applied jointly:

(a) the mathematical content explicitly addressed in the study's objectives and research questions and

(b) the construct coverage of the measurement instruments or observational protocols employed.

For instance, papers relying exclusively on the test of early mathematics ability (TEMA)-3 (Ginsburg & Baroody, 2003), whose informal subscale assesses only numbering, number comparison, informal calculation, and numerical concepts, were classified under numerical thinking. Papers using instruments with separate subscales for geometry alongside numerical content, such as the Ani Banani math test (ten Braak & Størksen, 2021) or the building blocks curriculum assessment (Clements & Sarama, 2007), were classified under both geometric and numerical thinking. Papers employing multidomain instruments or observational protocols covering numerical, geometric, algebraic, and metric content, such as the child math assessment (CMA) (Starkey et al., 2004) or the AIMK 0-3 rubric (Alsina & Roura, 2017), were classified across all relevant domains. Studies focused on probabilistic or statistical reasoning were classified under stochastic thinking. When a paper addressed more than one domain, it was counted in each; consequently, the sum of domain-specific totals

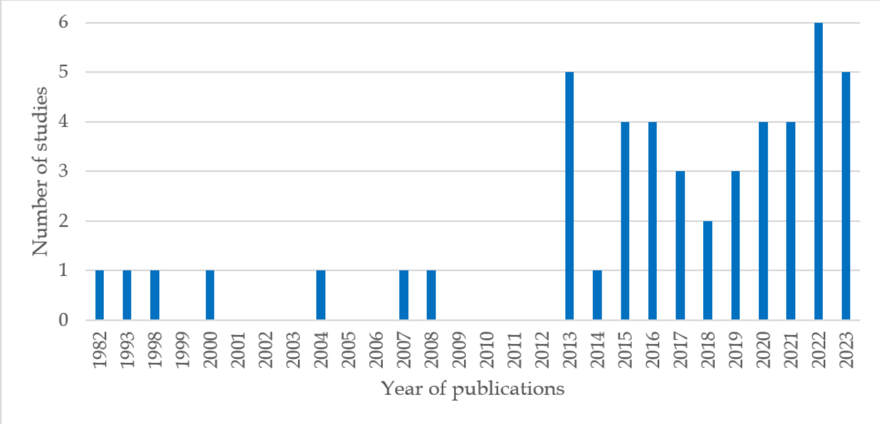

Figure 2. Publications per year in informal mathematics in early childhood (the authors' own elaboration)

Table 1. Authors' countries of institutional affiliation

Continent	Country	n	Percentage (%)
North America	USA	23	39.0
	Canada	4	6.8
Europe	Spain	10	16.9
	UK	4	6.8
	Greece	1	1.7
	France	1	1.7
	Norway	1	1.7
South America	Chile	4	6.8
	Peru	2	3.4
	Colombia	1	1.7
Asia	China	6	10.2
Oceania	Australia	2	3.4

Table 2. Sample sizes of the researches

Sample size	n	Percentage (%)
1-50	9	17.3
51-100	11	21.2
101-200	12	23.1
201-1,000	11	21.2
> 1,000	5	9.6
Not accurate	2	3.8
Not applicable	2	3.8

Note. Some studies used more than one sample, and others included only parents to respond & these sample sizes are being considered

exceeded 48. Discrepancies in domain assignment were resolved through discussion until consensus was reached. We show the instruments used, country, and study design for each paper, providing transparency on the basis for domain classification.

RESULTS

We analyzed 48 research papers, published between 1982 and 2023, which investigate various aspects of informal mathematics in early childhood (0-6 years).

Characteristics of the Study

As **Figure 2** shows, 83.7% papers meeting the inclusion criteria have been published since 2013. Before that year, only one or no paper per year was identified through our search criteria, which does not preclude the existence of related research using different terminology.

Another aspect considered was the contributions of authors from different countries to research on informal mathematics in early childhood. It can be observed (**Table 1**) that the highest percentage belongs to the United States, followed by Spain.

Regarding the research methods, while screening the papers we found out that 79.2% of the studies used a quantitative research method (e.g., experimental, predictive, explanatory, psychometric), in which data collection was mainly based on parent scales, standardized tests, and different specific tasks. To a lesser extent (16.7%), qualitative studies (e.g., case study, grounded theory, design research) were found with data generated mainly from interviews, parent reports, and observations. Regarding the number of participants in the different studies, we found that they greatly ranged from 1 to more than 2,000 (**Table 2**). Likewise, regarding the ages of the participants, we observed that the vast majority of empirical studies (87.2%) has focused on children between 3 and 6 years of age. On the other hand, only 10.6% studies focus exclusively on children between 0 and 3 years of age.

Across the reviewed papers, 12 studies have a primary focus on the family or home environment as a context for children's informal mathematical development. Within the numerical thinking domain, nine papers examine family-related variables: parental support for arithmetic skills (Yang et al., 2023), parental scaffolding during worksheet, game, and application activities (Huang et al., 2023), home numeracy experiences including counting and number games (Pan et al., 2023), the mediating role of self-regulation between parenting behaviors and mathematical development (Malaspina & Garcia, 2022), the contribution of home numeracy activities alongside ANS and mapping ability (Guo et al., 2021), parent-child number application activities (Zhang et al., 2020), parent involvement and neighborhood quality as predictors of

Table 3. Number of mathematical contents per paper

Number of mathematical contents	n	Percentage (%)
One mathematical content	34	70.8
Two mathematical contents	5	10.4
Three mathematical contents	0	0.0
Four mathematical contents	9	18.8
Five mathematical contents	0	0.0

Table 4. Mathematical thinking addressed in the paper

Mathematical thinking	n
Numerical thinking	45
Geometric thinking	14
Algebraic thinking	9
Metric thinking	9
Stochastic thinking	3

math achievement (Baker, 2015), formal and informal home learning activities and parental attitudes (Skwarchuk et al., 2014), and the effects of playing linear numerical board games (Siegler & Ramani, 2008). Within the geometric and numerical thinking domain, three additional papers address the family context: mathematical activities at preschool and home in Japan (Cave, 2021), play-based mathematics activities for head start families involving both numerical magnitude and shape-matching games (Ramani & Scalise, 2020), and a program to foster parental support for children's mathematical development including numerical and geometric content (Starkey & Klein, 2000). All 12 studies involve children aged 3 and older; none examined the family environment in relation to informal mathematics for children under 3 years.

Areas of Informal Mathematics in Early Childhood Education

Regarding the mathematical content in early childhood or types of mathematical thinking proposed in the theoretical foundations, most papers (n = 34) observed only focus on a specific area. Likewise, out of these investigations, 91.2% (n = 31) focused on numerical thinking and only 8.8% (n = 3) stochastic thinking. Regarding the investigations that have two or more mathematical contents, it can be evidenced that all of them have at least numerical and geometric thinking in their analysis, but none of them includes stochastic thinking. A summary of the findings is shown in **Table 3**.

Regarding the contents or mathematical thinking addressed in the papers, as explained by the authors, almost all the papers – as summarized in **Table 4** – include the analysis of numerical thinking in their studies, and few include stochastic, algebraic or metric thinking.

Among the 48 reviewed papers, different methodological approaches have been used to examine how informal mathematics can be defined and measured as a construct. Three studies directly address the dimensionality of informal mathematical abilities using psychometric modeling. Purpura and Lonigan (2013) used confirmatory factor analysis with the preschool early numeracy scales (PENS) (25 tasks across 3 subtests) in a sample of 393 preschoolers; they compared five competing models (one-factor, three two-factor variants, and a three-factor model) and found that the three-factor model, consisting of numbering, relations, and arithmetic operations, provided the best fit, and this structure was invariant across younger and older preschool children. Milburn et al. (2019) extended this work using categorical confirmatory factor analysis with the CMA (Starkey et al., 2004) in a sample of 1630 preschoolers from low-income families; they compared four models and found that the best-fitting model consisted of four factors: number and operations, measurement, geometry, and patterning, with the number and operations factor further decomposable into three first-order factors (numbering, operations, and relations). Malaspina and Arias (2022) applied a Rasch model to calibrate the 41 informal items of the TEMA-3 with 148 Peruvian preschoolers (ages 5 to 6), providing evidence for adequate psychometric properties of the informal mathematics dimension of the instrument.

In addition, two studies have taken a qualitative approach to defining the scope of informal mathematics for children under 3 years of age. Alsina and Roura (2017) designed, constructed, and validated a rubric (AIMK 0-3) for assessing acquisition levels of informal mathematical knowledge between 0 and 3 years, based on expert review by eight specialists in early childhood mathematics education. Alsina et al. (2023) subsequently applied this rubric to document and interpret the emergent mathematical actions of 12 children aged 1 to 2 years, providing preliminary observational data on mathematical content areas present before age 3. A more in-depth description of each type of thinking follows.

Numerical thinking

Of the total number of papers selected, 64.6% (n = 31) have aspects of numerical thinking as the only content of the study (**Table 5**), making this the most studied domain of informal mathematics.

Table 5. Papers analyzing numerical thinking only (n = 31)

Study	Topic of study	Age	n	Instrument(s)	Country	Design
Yang et al. (2023)	Parental support and children's arithmetic skills	4-5	90	Researcher-designed tasks (WOC, NLET, SCT, story problems); home activities questionnaire; number talk coding	China	Correlational

Table 5 (Continued).

Study	Topic of study	Age	n	Instrument(s)	Country	Design
Huang et al. (2023)	Parental scaffolding and children's numerical ability	5-6	96	TEMA-3 (Chinese version)	China	Correlational-observational
Coolen and Castronovo (2023)	Different memory types as a predictor of informal and formal mathematics (numerical skills)	5-8	133	TEMA-3; memory span tasks (visuospatial STM, visuospatial WM, verbal STM, verbal LTM)	UK	Correlational-predictive
Pan et al. (2023)	Home numeracy experiences and mathematical abilities	4-5	515	TCMA (expanded from TEMA)	China	Correlational
Malaspina and Garcia (2022)	Self-regulation as mediator between parenting and math development	5-6	85	TEMA-3; parenting questionnaire; self-regulation tasks	Peru	Cross-sectional, mediation
Estrada et al. (2022)	Relational concepts and selective attention as predictors of informal math	4-6	350	TEMA-3; RIAS	Colombia	Correlational-predictive
Liang et al. (2022)	ANS arithmetic training and informal math ability	4-5	90	TEMA-3; ANS tasks	China	Experimental (pre-post)
Malaspina and Arias (2022	Dimension of informal arithmetic development from TEMA-3	5-6	148	TEMA-3 (Rasch analysis)	Peru	Psychometric (Rasch)
Coolen et al. (2022)	Different ANS measures and executive functions in mathematics achievement (numerical skills)	4-7	174	TEMA-3; Panamath; EF tasks	UK	Correlational-predictive
Cerda et al. (2021)	Domain precursors of informal mathematical thinking	3-5	137	TEMA-3; RIAS	Chile	Correlational-predictive
Guo et al. (2021)	ANS, mapping ability, and home numeracy activities	4-5	110	TEMA-3; ANS tasks; mapping tasks; home numeracy questionnaire	China	Correlational-predictive
Aragón et al. (2021)	Cognitive precursors to informal math performance	4-5	158	TEMA-3, numerical estimation task, symbolic/non-symbolic comparison	Spain, Chile	Correlational-predictive
Zhang et al. (2020)	Parent-child number application activities	4-7	196	TCMA (adapted from TEMA); Parent activity questionnaire	China	Longitudinal
Namkung et al. (2019)	Growth trajectories of informal and formal arithmetic skills	4-7	281	TEMA-3 (informal and formal subscales)	USA	Longitudinal (growth modeling)
Aragón et al. (2019)	Cognitive precursors in informal arithmetic development	4-5	109	TEMA-3	Spain, Chile	Correlational-predictive
Cerda et al. (2018)	The open algorithm based on numbers (ABN) method	4-5	224	TEMA-3	Spain, Chile	Quasi-experimental
Szkudlarek and Brannon (2018)	Approximate arithmetic training in low achieving preschoolers	3-5	158	Modified NSS; PPVT-4; give-a-number task; letter span; EF tasks (DCCS + Stroop)	USA	Experimental (RCT)
Shanley et al. (2017)	Early number skills gains and mathematics achievement	4-5	582	RAENS; TEMA-3; SAT-10; ASPENS	USA	Quasi-experimental
Zhang et al. (2017)	Role of early language abilities on math skills	5-7	2,012	TEMA-3; language measures	China	Correlational-predictive
Libertus et al. (2016)	Precision of mapping between number words and ANS	5-8	51	TEMA-3; number estimation task; ANS dot comparison	USA	Cross-sectional
Purpura and Napoli (2015)	Early numeracy and literacy	3-5	180	PENS; literacy measures	USA	Correlational
Baker (2015)	Parent involvement, neighborhood quality, and math achievement	4-6	1,202	Secondary data (NICHD study); math scores at K entry	USA	Correlational (secondary data)
Skwarchuk et al. (2014)	Formal and informal home learning activities	4-5	183	Researcher-designed numeracy/literacy tasks; parent questionnaires	Canada	Longitudinal
Libertus et al. (2013)	Numerical approximation abilities and math	3-7	85	TEMA-3; REMA; Panamath (ANS)	USA	Longitudinal
Purpura et al. (2013)	Transition from informal to formal math knowledge	3-6	393, 206	PENS; WJ-III Calculation	USA	Longitudinal (1 year)
Clark et al. (2013)	Executive control and developing math competence	3-5	228	TEMA-3; WJ-III applied problems; EF task battery	USA, Canada	Longitudinal
Purpura and Lonigan (2013)	Informal numeracy skills: structure of numbering, relations, arithmetic	3-5	393	PENS (25 tasks, 3 subtests)	USA	Cross-sectional (CFA)
Siegler and Ramani (2008)	Linear numerical board games and numerical development	4-5	58, 36	Researcher-designed (board game; number tasks)	USA	Experimental (RCT)
Ginsburg and Pappas (2004)	Young children's informal addition and subtraction	4-6	102	Clinical interview (Piagetian tasks)	USA	Cross-sectional
Davis and Ginsburg (1993)	Roles of schooling and social class in informal math cognition	3-5	1,008	Clinical interview (Piagetian tasks)	USA, Benin, Korea	Cross-cultural comparison
Baroody and Ginsburg (1982)	Preschoolers' informal math skills (comparisons, counting, screening)	NA	NA	Clinical interview; observation	USA	Theoretical/qualitative

Note. NA: Not accurate

All 31 studies are quantitative and none involve children under 3 years of age; sample sizes range from 48 (Davis & Ginsburg, 1993) to 2012 (J. Zhang et al., 2017), with most focusing on children aged 3 to 6. The

Table 6. Papers related to geometric and numerical thinking (n = 5)

Study	Topic of study	Age	n	Instrument(s)	Country	Design
ten Braak and Storksen (2021)	Psychometric properties of a math test (numeracy and geometry)	4-7	243, 691 and 1282	Ani Banani math test (numeracy + geometry subscales)	Norway	Psychometric validation
Cave (2021)	Mathematical activities at preschool and home	4-5	NA	Observation; parent questionnaire; teacher questionnaire	Japan	Qualitative observational
Ramani and Scalise (2020)	Play-based math activities for head start families (numerical and shape games)	3-5	39	Researcher-designed (magnitude card game + shape/color game); number tasks; shape tasks	USA	Experimental (RCT)
Clements and Sarama (2007)	Effects of building blocks preschool math curriculum (number and geometry)	3-5	68	Building blocks assessment; REMA	USA	Experimental (RCT)
Starkey and Klein (2000)	Parental support for math development (numerical and geometric)	4-5	28 and 31	Researcher-designed (number + geometry tasks); parent training	USA	Quasi-experimental

Note. NA: Not accurate

most frequently used instrument is some version or adaptation of the TEMA, TEMA-2, TEMA-3 (Ginsburg & Baroody, 1983, 1990, 2003, 2007), employed in 21 of the 31 papers. Other instruments include the PENS (Purpura & Lonigan, 2013) and the CMA (Starkey et al., 2004; used in Milburn et al., 2019).

Among the empirical studies, a first group investigates associations between different factors and early numeracy skills: the impact of numerical learning experiences at home or parental support (e.g., Baker, 2015; Pan et al., 2023; Skwarchuk et al., 2014; Yang et al., 2023); approximate number system training (e.g., Guo et al., 2021; Liang et al., 2022; Libertus et al., 2013, 2016); or related cognitive processes in informal mathematics (e.g., Aragón et al., 2021; Cerda et al., 2021; Coolen & Castronovo, 2023). A second group examines links between numeracy and verbal skills (e.g., Aragón et al., 2019; Purpura & Napoli, 2015); measurement properties of informal numeracy (e.g., Malaspina & Arias, 2022; Purpura & Lonigan, 2013); and learning in children with mathematical difficulties (e.g., Namkung et al., 2019; Shanley et al., 2017). The predominance of this domain in the literature likely reflects the availability of standardized instruments (particularly the TEMA) and the strong predictive validity of early numerical skills for later math achievement; however, the absence of studies with children under 3 represents a gap in understanding the earliest developmental trajectories.

Geometric thinking

All five papers that addressed geometric thinking did so in combination with numerical thinking (**Table 6**). This co-occurrence reflects the design of the instruments and curricula used in these studies rather than a theoretical position about domain interconnection: the Ani Banani math test includes separate numeracy and geometry subscales aligned with the Norwegian ECEC framework (ten Braak & Størksen, 2021); Ramani and Scalise (2020) used separate numerical and shape-matching games as two experimental conditions; and the building blocks curriculum covers both number and geometry as distinct content areas (Clements & Sarama, 2007). Cave (2021) and Starkey and Klein (2000) studied mathematical activities broadly, including both numerical and spatial content.

These studies use both quantitative and qualitative approaches, with ages ranging from 1 to 8 years. Their findings highlight the importance of numerical, spatial, and shape activities in both preschool and home environments (Cave, 2021; Starkey & Klein, 2000), the benefits of play activities involving number and shape knowledge for families (Ramani & Scalise, 2020), the effectiveness of the building blocks curriculum in improving understanding of geometric concepts (Clements & Sarama, 2007), and the adequate psychometric properties of the Ani Banani math test for measuring both numerical and geometric skills (ten Braak & Størksen, 2021). The limited number of papers and the absence of studies examining geometric thinking independently highlight a significant gap in the literature.

Algebraic thinking and metric thinking

No paper addresses only algebraic or metric thinking, but 7 of them include it together with geometric and numerical thinking (**Table 7**). These studies employ both qualitative and quantitative approaches across a wide age range. Some focus on children under 3 years of age (Alsina & Berciano, 2020; Alsina & León, 2016), while others include preschoolers aged 4 and older (Milburn et al., 2019). Instruments range from TEMA-3 adaptations and the CMA (Starkey et al., 2004) to researcher-designed observation protocols, rubrics for assessing informal mathematical knowledge in children under 3 (Alsina & Roura, 2017; Alsina et al., 2023), and ethnographic methods (Macmillan, 1998).

Table 7. Papers related to algebraic, metric, geometric and numerical thinking (n = 9)

Study	Topic of study	Age	n	Instrument(s)	Country	Design
Alsina et al. (2023)	Assessment of emergent mathematics (0-3 years)	1-2	12	Rubric AIMK 0-3; semi-structured interview	Spain	Qualitative observational
Alsina and Berciano (2020)	Developing informal mathematics in early childhood	0-3	87	Observation protocol (mathematical actions during manipulation)	Spain	Quantitative
Milburn et al. (2019)	Dimensionality of informal mathematical abilities	3-6	1630	CMA (35 items, 9 tasks)	USA	Cross-sectional (CCFA)
Alsina and Roura (2017)	Acquisition levels of informal math knowledge (0-3 years)	0-3	NA	Rubric AIMK 0-3 (expert validation, 8 experts)	Spain	Instrument development
Barnes et al. (2016)	Effects of tutorial interventions in math and attention	3-6	541	TEMA-3; CMA; attention tasks	USA	Experimental (RCT)
Alsina and León (2016)	Mathematical actions triggered by artistic installations (0-3)	0-3	85	Observation protocol	Spain	Mixed methods (convergent)
Wernet and Nurnberger-Haag (2015)	Young children's beliefs about mathematics	3	1	Semi-structured interviews; drawing tasks	USA	Qualitative (case study)
Acosta and Alsina (2015)	Mathematical actions within a reflective teaching atmosphere	2-3	16	Observation protocol; teaching reflection	Spain	Qualitative (action research)
Macmillan (1998)	Informal settings and children's use of mathematical concepts	NA	NA	Ethnographic observation; audio recording	Australia	Ethnographic

Note. NA: Not accurate

Table 8. Papers related to stochastic thinking (n = 3)

Study	Topic of study	Age	n	Instrument(s)	Country	Design
Novo et al. (2020)	Statistics and probability to promote sustainability	5-6	24	Researcher-designed (RME-based classroom activities)	Spain	Qualitative descriptive
Makar (2016)	Informal statistical inference in the early years	5-6	22	Researcher-designed inquiry tasks	Australia	Qualitative descriptive (teaching practice)
Nikiforidou et al. (2013)	Intuitive and informal knowledge in probabilistic thinking	4-6	90	Researcher-designed probability tasks	Greece	Quantitative

Some studies focus on exploring the emergent mathematics that children may be learning informally (Alsina & Berciano, 2020) and on analyzing the dimensions present in the development of informal mathematics in preschool-aged children (Alsina & Roura, 2017; Milburn et al., 2019), including content associated with algebraic thinking (e.g., early classifications, patterns, and initial transformations) and metric thinking (e.g., intuitive knowledge of magnitudes and first direct comparisons). Other studies evaluate the impact of early interventions and attention stimulation in underachieving preschoolers (Barnes et al., 2016), explore mathematical actions performed by 1- to 3-year-old children in different contexts (Alsina & León, 2016), and investigate young children's beliefs about mathematics before school entry (Wernet & Nürnberger-Haag, 2015). Acosta and Alsina (2015) document and analyze informal mathematical content from specific educational proposals and examine the transformation of teaching practice in these contexts. Macmillan (1998), using an ethnographic approach, shows how children incorporate mathematical concepts, including numbers, shapes, patterns, and spatial relationships, into their language and behavior during play.

Stochastic thinking

The three papers found exclusively analyze this domain (**Table 8**), and none involve participants 0 and 3 years. Two papers use qualitative methodology (Makar, 2016; Novo et al., 2020;), and the third is quantitative (Nikiforidou et al., 2013). All three rely on researcher-designed tasks and observation protocols rather than standardized assessments.

Novo et al. (2020) show that teaching practices from realistic mathematics education promote sustainability education through statistics and probability. The other studies found that children mobilize prior intuitions about probabilistic concepts, can make sensible estimates, and are able to make informal statistical inferences (Makar, 2016; Nikiforidou et al., 2013). Stochastic thinking is the least studied domain, and the very small number of papers (n = 3) combined with the complete absence of studies with children under 3 highlight this as the largest gap in the current literature.

DISCUSSION

This study has presented a systematic review, from 1982 to 2023, focusing on research from the WoS and Scopus databases related to informal mathematics in early childhood. Following the PRISMA method (Page et al., 2021), the systematic review focused on two main issues: the descriptive characteristics of the studies and the mathematical content area.

Regarding the descriptive characteristics of the studies, a relevant finding is the increase in the production of studies since 2013, which is consistent with that mentioned by Alsina (2020), Baroody et al. (2006) and Sarama and Clements (2009), who highlight a growing agreement, interest and effort in research in early childhood mathematics education. However, it has been noted that most studies focus on children aged 3 to 6, which highlights the need to generate more research papers on younger children and in the family environment, according to Lehrl et al. (2020).

A quarter of the reviewed papers examined the family or home environment as a context for informal mathematical development. The methodological approaches range from correlational designs examining associations between home numeracy activities and children's outcomes (Pan et al., 2023; Skwarchuk et al., 2014) to observational studies of parent-child interactions during mathematical activities (Cave, 2021; Huang et al., 2023) and intervention studies that empower parents as facilitators of mathematical learning (Ramani & Scalise, 2020; Siegler & Ramani, 2008; Starkey & Klein, 2000). Some studies highlight the frequency of numeracy-related activities as a predictor (Pan et al., 2023), others emphasize the quality or type of parental scaffolding over its frequency (Huang et al., 2023; Yang et al., 2023), and still others demonstrate the effectiveness of structured play-based interventions that families can implement at home (Ramani & Scalise, 2020; Siegler & Ramani, 2008). Malaspina and Garcia (2022) further showed that the relationship between parenting behaviors and mathematical development is mediated by children's self-regulation skills, suggesting that the pathways through which the family environment influences math learning may be indirect. Importantly, all of these studies focus on children aged 3 to 6, leaving the role of the family environment in the mathematical development of children under 3 largely unexplored. This represents a significant gap, given the emphasis placed by Geist (2014) and Alsina (2015) on the role of parents and caregivers in emergent mathematics from birth.

The data from the systematic review on the mathematical content of the studies have provided relevant findings. In relation to numerical thinking, the results reveal a large amount of research papers that focus on this domain. If mathematical thinking develops as an interrelated system encompassing numerical, geometric, algebraic, metric, and stochastic thinking, then a research base concentrated on a single domain constrains our ability to understand how these dimensions interact and develop jointly during early childhood. This isolation may also have practical consequences: curricula and assessment tools derived largely from numerically-focused evidence risk underrepresenting other forms of informal mathematical reasoning that children display from an early age. We therefore consider that this focus on a single domain is not merely a descriptive finding, but a substantial gap that must be considered for future research and interventions related to informal mathematics as a multidimensional construct.

While the NCTM (2000) standards place Number and Operations as a foundational content area, this does not imply that other domains are less important for children's mathematical development. Rather, the concentration of research on numerical thinking reflects a research trend that has left other content areas comparatively understudied (Sarama & Clements, 2009). The results confirm the idea that informal mathematical skills, such as counting, estimating and engaging in number games, are fundamental in the development of a solid foundation for later mathematical skills (Clark et al., 2013; Malaspina & Garcia, 2022; Siegler & Ramani, 2008). In addition, parents' active participation in informal numerical activities has been identified as a key factor in improving their children's numerical skills (Cerda et al., 2021; Liang et al., 2022; Pan et al., 2023; Zhang et al., 2020).

Although no studies were found focusing exclusively on geometric thinking, the data reviewed confirm that this is the second most frequently studied domain consistent with the emphasis placed on geometry by NCTM (2000) and Sarama and Clements (2009). All five papers that include geometric content also address numerical thinking, which likely reflects the multidomain design of the instruments and interventions used (e.g., Clements & Sarama, 2007; ten Braak & Størksen, 2021), rather than a deliberate research focus on domain interconnection. For instance, the Ani Banani math test includes separate numeracy and geometry subscales, Ramani and Scalise (2020) employed distinct numerical and shape-matching game conditions, and the building blocks curriculum (Clements & Sarama, 2007) covers both as distinct content areas. Across these studies, findings suggest that children begin to develop geometric concepts from an early age, such as identifying and analyzing simple shapes and understanding spatial relationships among objects (Alsina, 2015; Sarama & Clements, 2009), and that close collaboration between school and family is important for providing learning opportunities that encourage the exploration and manipulation of objects and shapes in children's environments (Cave, 2021; ten Braak & Størksen, 2021). Future studies that isolate geometric thinking as an independent construct could clarify whether informal geometric skills develop in parallel with, or dependently on, numerical skills.

In relation to algebraic and metric thinking, few studies analyze them from an informal mathematics perspective. This reveals that these types of thinking have not been the focus of the research despite the evidence, as shown by Milburn et al., (2019), that informal mathematical skills have a broader structure that encompasses three additional factors, which are measurement, geometry, and patterns; this approach strongly supports the idea of including activities that promote more types of mathematical thinking in teaching (Acosta & Alsina, 2015), assessment (Alsina & Roura, 2017) and early interventions in mathematics (Barnes et al., 2016). Wernet and Nurnberger-Haag (2015) highlight the importance of recognizing that young children's beliefs about mathematics often do not match their rich mathematical activities, emphasizing the need to broaden our understanding of mathematics as a cultural activity.

Regarding stochastic thinking in early childhood, the few studies identified focus on children aged 3 to 6 and highlight the importance of providing meaningful experiences to develop an understanding of statistics and probability at these ages. In addition, they highlight the connection between informal understanding and formal instruction in this domain (Makar, 2016; Nikiforidou et al., 2013; Novo et al., 2020). These results are in line with what Sarama and Clements (2009) point out about the importance of gradually developing understanding of concepts related to expectation and variation. However, the few studies found in this field reveal a need for more extensive research and a more specific theory to explore how children at younger ages begin to develop an understanding of probability and the ability to analyze data informally.

CONCLUSIONS

Our main conclusion is that the result of the systematic review shows the relevance of research on informal mathematics and that this field is a fundamental part of children's cognitive development from birth. In this line, Alsina (2015), Clements and Sarama (2009) and Geist (2014) state that children begin to develop their mathematical thinking from their first days of life through interactions with their physical and social environment. In this sense, the 48 papers selected may seem few in such a long period, but it should be emphasized that not all studies dealing with children's mathematics have been considered, but rather those dealing with children's informal mathematics.

The present study has limitations due to the language of the selected papers (English and Spanish). While this decision allowed us to ensure linguistic consistency in coding and to highlight Ibero-American contributions, it likely excluded relevant studies published in the local languages of countries with well-established early childhood education research traditions, for instance, Nordic countries (e.g., Finland, Norway, and Sweden) and several Asian countries (e.g., Japan, South Korea, and China). Future systematic reviews could incorporate translation strategies or collaborate with multilingual research teams to capture this literature and provide a more globally representative picture of informal mathematics research.

The focus of this study has been to analyze the role of informal mathematics in the development of early mathematical thinking; in that sense, all search terms include this construct, which may have led to the omission of other papers on early mathematics that do not explicitly include this construct. Therefore, these findings should be complemented by other previous and/or subsequent reviews that consider other terms using broader search strategies.

Furthermore, although WoS and Scopus together provide broad multidisciplinary coverage, they may not represent the totality of the relevant literature. The inclusion of specialized databases such as ERIC and PsycINFO could capture additional relevant studies, particularly education practitioner-oriented journals and regional publications (Gusenbauer, 2022; Martín-Martín et al., 2018); this trade-off was accepted in exchange for the academic quality and methodological consistency that WoS and Scopus jointly provide across the screening and coding stages.

Despite these limitations, the systematic review provides an updated and rigorous overview of research on informal mathematics in early childhood, which contributes to current knowledge in this field. The present study supports the idea that the development of mathematical thinking begins at birth and is manifested through everyday interactions with the environment. The findings have shown that children acquire an early understanding of numerical, geometric, algebraic, metric, and stochastic concepts, which is consistent with NCTM (2000) and has significant implications for early childhood mathematics education.

In the future, research on informal mathematics in early childhood should be expanded and diversified, focusing on less explored areas such as stochastic, algebraic and metric thinking and on the youngest population of children (0 to 3 years) to better understand informal mathematical development at this crucial stage of life. Finally, considering that the results highlight the importance of play-based mathematical activities and school-family collaboration in the development of early mathematical skills, it will be necessary to further investigate the role of play-based educational interventions with the presence of parents and teachers as active partners in the mathematical education of children.

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Asterisk denotes inclusion in the database.

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