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Self-regulation and problem solving in early childhood: the mediating role of number sense

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Abstract

The aim of this study is to examine the relationships among self-regulation, number sense, and problem-solving skills, and to assess whether number sense plays a mediating role in the interaction between self-regulation and problem-solving skills. The study was conducted in line with the quantitative research approach, using a correlational survey design. The study included a total of 244 children aged 60–72 months attending public independent kindergartens and preschools in a province in the northeastern anatolia region of Türkiye. Data were collected through the Number Sense Test, the Self-Regulation Skills Scale, and the Problem Solving Scale. The measurement tools used in the study were found to be valid and reliable. The findings indicated that self-regulation was found to be significantly associated with, and to predict, children's problem-solving skills and number sense performance. Additionally, number sense partially mediated this predictive relationship. The proposed model and findings of the study were compared with the existing literature, and new insights were gained regarding the relationships among self-regulation, number sense, and problem-solving skills. These results are expected to contribute to the development of educational programs.

Keywords Number sense · Self-regulation · Problem solving · Early childhood education

Introduction

Early childhood represents a critical period for children's personal development. The development of self-regulation and problem-solving skills during early childhood plays a decisive role in children's academic achievement and the acquisition of essential life skills. Self-regulation abilities developed in this period are closely associated with children's competencies in foundational domains such as mathematics. Moreover, longitudinal evidence indicates that early self-regulation skills have enduring effects on later outcomes, including educational attainment and career success (McClelland et al., 2013).

It is widely emphasized that self-regulation and problem-solving skills acquired in early childhood are predictively associated not only with children's later academic achievement but also with their social and emotional well-being. The early acquisition of these skills enables children to develop vital competencies such as establishing positive interpersonal relationships (Gys et al., 2024), coping with stress, regulating emotions, and developing empathy (Bockmann & Yu, 2023). These competencies play a crucial role in supporting adaptive functioning and life skills in later developmental stages.

Establishing number concepts in early childhood enables children to develop mathematical understanding and problem-solving abilities in a flexible and adaptive manner. Early numerical learning involves the ability to reason about quantities, numerical relationships, and symbolic representations across different contexts, which collectively contribute to the development of number sense. It is emphasized that children should acquire number sense during early childhood to support the development of quantitative thinking skills. Number sense that emerges in the early years is a

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significant predictor of early mathematical competence and later academic performance (Jordan et al., 2007, 2022).

Establishing number sense on a solid foundation in early childhood is therefore considered critical for later mathematics achievement. Empirical evidence further indicates that early number sense predicts standardized mathematics test performance and serves as an early indicator of future mathematical learning difficulties (Jiang &Wang, 2024; Jordan et al., 2010). In this respect, research focusing on number sense—recognized as a core component of mathematical competence—holds particular importance for understanding children's early learning trajectories.

There are various studies detailing the characteristics and components of number sense. According to Griffin (2004), number sense is "*easy to recognize but difficult to define and hence*, *to teach*". Therefore, several theoretical frameworks have been used to define and analyze number sense, and this has led to different operational meanings (Berch, 2005). According to Berch (2005), the different definitions of number sense can be explained by the fact that cognitive scientists and mathematics educators define this concept in different ways.

These variations in defining number sense underline the complexity and interdisciplinary nature of the construct, which sits at the intersection of cognitive development, early mathematics education, and educational psychology. Consequently, in order to fully understand how foundational competencies in early childhood support later learning and academic success, it is essential to explore not only the development of number sense, but also its relationship with other key constructs such as self-regulation and problem-solving.

Therefore, the following literature review focuses on a comprehensive examination of three interrelated constructs that are vital in early childhood: self-regulation, problem-solving, and number sense. These constructs are discussed in light of their developmental significance, theoretical underpinnings, and empirical relationships, particularly in the context of early mathematical thinking and learning processes.

Self-regulation

Self-regulation refers to individuals' capacity to monitor, evaluate, and adapt their thoughts, emotions, and behaviors in alignment with internal goals and external demands (Zimmerman, 2000). As a multifaceted construct, self-regulation integrates cognitive, motivational, and behavioral strategies that support learners' active management of learning processes and academic success, particularly within developmental and educational contexts (Pintrich, 2000; Zimmerman & Schunk, 2011; Blair & Raver, 2015).

Originally examined within social-emotional domains, self-regulation has more recently been conceptualized as a foundational mechanism linking emotional, cognitive, and academic development in early childhood (Blair & Raver, 2015; Wesarg-Menzel et al., 2023).From a developmental standpoint, self-regulation encompasses processes such as goal setting, strategic planning, attentional control, emotional regulation, and reflective thinking, which interrelate and develop over time to support adaptive functioning in both academic and non-academic settings (Wesarg-Menzel et al., 2023; Trautner & Pinquart, 2025).

Self-regulated learners are individuals who are aware of their own learning processes and are able to actively manage them through goal setting, strategic planning, and self-monitoring (Zimmerman, 2000; Trautner & Pinquart, 2025). In educational contexts, self-regulation supports students in sustaining attention, effectively utilizing learning resources, and persisting in the face of academic challenges (Zimmerman, 2011). Beyond academic achievement, these self-regulatory capacities contribute to adaptive functioning and long-term success across personal, social, and professional domains (Wesarg-Menzel et al., 2023).

Zimmerman and Pons (1988) proposed a comprehensive model of self-regulated learning strategies, structured into three cyclical phases: forethought, performance, and self-reflection. In the forethought phase, students set learning goals and select appropriate strategies; in the performance phase, they monitor their progress and adjust strategies as needed; and in the self-reflection phase, they evaluate outcomes and use insights to inform future learning. This model outlines the key strategies involved in self-regulation, including:

- Goal setting strategies that support the articulation of specific learning objectives;
- Learning strategies that assist in selecting and organizing learning materials;
- Performance control strategies that enable monitoring and adaptive behavior during task engagement;
- Self-reflection strategies that foster critical evaluation of outcomes and metacognitive growth.

Research consistently highlights that self-regulation is a significant predictor of academic achievement across age groups, including early childhood. For example, meta-analyses indicate that students who effectively deploy self-regulation strategies exhibit higher levels of engagement, motivation, and academic performance (Zimmerman & Schunk, 2011). Moreover, these strategies help cultivate learners' autonomy, resilience, and self-efficacy—qualities that are foundational to lifelong learning and problem solving.

In summary, self-regulation is not merely a personal trait but a dynamic, teachable competency that enables children to take ownership of their learning processes. Supporting the development of self-regulation skills in early childhood lays a crucial foundation for later academic achievement and cognitive flexibility, particularly in domains such as mathematics, where sustained attention, adaptive reasoning, and strategic thinking are essential.

Dimensions of Self-Regulation

Self-regulation is a multifaceted construct encompassing a broad range of skills required to manage one's thoughts, emotions, and behaviors in pursuit of internal goals and adaptation to changing environmental demands. Due to its complex and multidimensional nature, various theoretical models have been proposed to classify the components of self-regulation across different psychological frameworks.

For instance, Blair and Raver (2015) conceptualize self-regulation as a developmental construct involving the control of automatic responses, delay of gratification, motor regulation, and sustained attention, all of which are foundational for adaptive functioning in early childhood. Gys et al. (2024) empirically demonstrate that self-regulatory processes are closely associated with children's social competence and behavioral adjustment during early developmental periods, whereas Zimmerman (2000) frames self-regulation primarily in terms of goal-directed and strategic behavior. More recent integrative perspectives describe self-regulation as a multidimensional construct encompassing cognitive, behavioral, and emotional domains, reflecting its complex and interrelated nature across developmental contexts (Blair & Raver, 2015; Wesarg-Menzel et al., 2023).

Despite differing conceptualizations, contemporary research widely conceptualizes self-regulation as a multidimensional construct encompassing cognitive, behavioral, and emotional regulation processes. These dimensions interact dynamically to support children's adaptive functioning and learning across developmental contexts (Blair & Raver, 2015; Wesarg-Menzel et al., 2023). In the context of the present study, which examines self-regulation in relation to number sense and problem-solving skills, particular emphasis is placed on cognitive regulation due to its direct relevance to early mathematical learning and the development of executive functioning.

Cognitive regulation, also referred to as attention regulation in the literature, refers to the processes that enable individuals to selectively focus, maintain, and shift attention as needed, and to manage working memory and executive control functions. These skills are commonly conceptualized as interrelated components of executive functioning, including attention control, working memory, and inhibitory control (Diamond, 2013).

Attention regulation involves the ability to distinguish between relevant and irrelevant stimuli, sustain attention over time, and direct cognitive resources toward goal-oriented tasks (Diamond, 2013; Blair & Raver, 2015). Executive attention, as a more advanced level of attentional processing, pertains to the capacity to focus selectively on specific stimuli and to shift that focus when contextually necessary. This subcomponent enables individuals to inhibit attention to distracting stimuli and instead redirect focus toward goal-congruent targets (Diamond, 2013; Blair & Raver, 2015; Wesarg-Menzel et al., 2023).

Working memory serves as a central cognitive mechanism that enables the temporary storage and manipulation of information required for complex cognitive tasks (Baddeley, 2012). By maintaining task-relevant information and supporting the regulation of attentional focus, working memory plays a critical role in goal-directed behavior. In early childhood, these processes allow children to resist salient distractions and sustain attention on cognitively demanding tasks, thereby supporting self-regulation and learning (Diamond, 2013; Baddeley, 2012; Blair & Raver, 2015).

One of the most prominent demonstrations of inhibitory control—a subcomponent of cognitive regulation—is found in the well-known "Marshmallow Test" conducted by Mischel (2014) with preschool children. In this experiment, children were told they could receive a second marshmallow if they resisted eating the first one placed in front of them. The ability to delay gratification in this context reflects the core mechanism of inhibitory control, where the child suppresses an immediate impulse (eating the marshmallow) in favor of a more desirable but delayed outcome. Inhibitory control refers to the ability to deliberately suppress dominant, automatic, or prepotent responses in order to act in accordance with goals or task demands (Diamond, 2013). In this case, the child's ability to refrain from eating the marshmallow requires active suppression of both thought and behavior that are misaligned with the anticipated reward. Interestingly, although no explicit self-regulation strategies were taught to the children in Mischel's study, many demonstrated the spontaneous use of personal coping techniques to manage their impulses. These included behaviors such as closing their eyes, distracting themselves with nearby objects, or engaging in self-directed verbalizations. Such behaviors are indicative of effortful control, a facet of executive attention that enables individuals to override dominant responses and voluntarily shift focus toward goal-relevant stimuli (Diamond, 2013; Wesarg-Menzel et al., 2023).

Executive functions, closely linked to the aforementioned components, include a set of higher-order cognitive skills that support the planning, initiation, monitoring, and regulation of goal-directed behavior. These include inhibiting impulsive responses, organizing information, shifting

attention as needed, and maintaining task persistence. Executive functions are foundational not only for cognitive development but also for behavioral control, motor coordination, and socio-emotional competence (Diamond, 2013). Research indicates that executive functions are also significantly related to mathematics achievement in early childhood, with numeracy skills playing a mediating role in this relationship (Chan & Scalise, 2022; Fuhs et al., 2016; Hassinger-Das et al., 2014; Zhang et al., 2023). However, detailed explanations of these relationships, including the specific models and hypotheses tested, are provided in the relevant sections of this study.

In early childhood, cognitive regulation and its associated executive functions form the cornerstone of school readiness and are strongly linked to emerging mathematical skills, such as number sense and problem-solving. Given its role in sustaining attention, managing task-relevant information, and inhibiting distractions, cognitive regulation is considered a central mechanism through which young children engage in and benefit from learning experiences in both structured and unstructured contexts.

Problem solving

Problem solving is commonly conceptualized as a cognitive and behavioral process through which individuals attempt to achieve a goal when an immediate or previously learned solution is not available. Such situations typically require the coordinated use of higher-order thinking skills, including analysis, reasoning, and flexible strategy use (Zimmerman, 2000; Pintrich, 2000). In early childhood, problem solving constitutes a critical developmental domain through which children begin to acquire essential life skills such as decision making, self-regulation, and adaptive reasoning, all of which support successful engagement with learning demands and everyday challenges (Blair & Raver, 2015; McClelland & Cameron, 2019; Elliott et al., 2022).

Although early problem-solving abilities may be influenced by children's initial cognitive dispositions, a substantial body of research suggests that these skills are largely learnable and can be systematically developed through experience and instructional support (Zimmerman, 2000; Zimmerman & Schunk, 2011). During early childhood, the acquisition of problem-solving skills enhances children's capacity to process information, select appropriate strategies, and apply knowledge across contexts, thereby supporting both academic learning and everyday functioning.

From a developmental perspective, problem solving in young children is a dynamic and evolving process that relies on structured cognitive and self-regulatory strategies. Within self-regulated learning frameworks, effective problem solving is characterized by goal setting, strategic planning, monitoring, and reflective evaluation, processes that are closely intertwined with children's developing self-regulation skills (Zimmerman & Schunk, 2011; Pintrich, 2000).

Furthermore, the development of number sense plays a central role in facilitating effective problem solving during early childhood. Number sense, which refers to children's intuitive understanding of numbers, quantities, and numerical relationships, supports flexible thinking and enables the selection of solution strategies that are appropriate to the structure of a problem (McIntosh et al., 2005). Empirical studies further indicate that children who demonstrate stronger number sense skills are better able to analyze quantitative problems and apply effective problem-solving strategies, particularly in mathematically demanding contexts (Louange & Bana, 2010).

In addition, the interrelationship between self-regulation and number sense further enhances children's problem-solving capacities. Self-regulated learners are more likely to monitor their progress, adjust strategies when necessary, and persist in the face of challenge—behaviors that are particularly relevant for mathematical problem solving (İvrendi, 2011, 2016a). Accordingly, in the present study, number sense is conceptualized as a mediating variable in the relationship between self-regulation and problem-solving skills in early childhood.

Number sense

Number sense involves developing useful strategies for making mathematical decisions and processing numbers. The concept of number sense includes the ability to perform complex calculations and the capacity to understand the importance of numbers and to "feel" numbers in a non-algorithmic way (Berch, 2005). In this regard, as stated by Pittalis et al. (2018), one of the empirical studies that best explain the number sense skills of children in early childhood was conducted by Jordan et al. (2006), who used empirical evidence to show that number sense is a two-dimensional concept. These two-dimensional models are similar to Berch's (2005) model of lower- and higher-order number sense characteristics and Okamoto and Case's (1996) factors. Jordan and colleagues (2006, 2007, 2008, 2010) developed a model that has been validated in multiple studies with students from kindergarten up to third grade. In this model, basic number skills—such as counting, number recognition, number knowledge, estimation, number patterns, and non-verbal calculation—constitute the first dimension. The second dimension includes conventional arithmetic components, such as story problems and number combinations (Jordan et al., 2006, 2007, 2008, 2010). The basic number skills factor corresponds to Berch's (2005)

lower-order number sense, which defines basic quantity knowledge, and to Okamoto and Case's (1996) concept of quantity discrimination, while the second dimension corresponds to secondary skills that support traditional educational activities and higher-order number sense (Jordan et al., 2006, 2007).

Van Den Heuvel-Panhuizen (2008) defines the development of number sense in kindergarten children across three levels. The foundational numerical knowledge acquired prior to kindergarten is referred to as Level 0. Although individual differences may be observed among children at the point of school entry, this period is generally classified as Level 0 within the model. The development of number sense during the kindergarten year is described as progressing through Level 1, Level 2, and Level 3, thus outlining a four-level developmental framework in total. This model provides a systematic structure for monitoring early mathematical development.

In addition to the basic level existing before kindergarten education, the three general stages developed during kindergarten education are stated below (see Fig. 1):

- First stage- This is the basic calculation level where counting and simple addition and subtraction calculations are performed based on the environmental context. At this level, students learn to count by associating numbers with examples from daily life, arrange numbers, and practice solving simple mathematical problems.
- Second stage- This level involves object-based counting and calculation of simple addition and subtraction problems in which objects are shown and then hidden. At this stage, students learn to count using concrete objects and then perform simple mathematical operations by remembering the images of these objects.
- Third stage- This is the level where pure counting and addition and subtraction calculations are performed using a missing variable. At this stage, students encounter abstract concepts more frequently and learn to solve mathematical problems using missing information.

Concepts such as counting, number and number sense develop in conjunction with each other over time. Furthermore, the components of number sense are related both to each other and to other mathematical skills, and these acquired skills can mutually interact (Pittalis et al., 2018). Since basic number sense skills are generally acquired by children between the ages of 5–6, this age range is of great importance for the development of children's mathematical skills. Failure to acquire basic number sense skills at this stage may lead to difficulties in mathematical skills at later ages. Therefore, the development of number sense in early childhood is of critical importance.

Number sense, which is one of the cornerstones of mathematical thinking, is an important skill that should be developed in early childhood. Despite this, the effect of number sense on self-regulation and problem-solving skills and whether number sense plays a mediating role in the relationship between these two skills has not yet been adequately examined. This has resulted in limited empirical findings for structuring educational programs to support number sense and these skills (Gözüm et al., 2024).

The aim of this study is to examine the relationships among number sense, self-regulation, and problem-solving skills in early childhood, as well as to investigate the potential mediating role of number sense in the interaction between self-regulation and problem-solving skills. İvrendi (2011, 2016a, b) has explored the relationship between the development of number sense and self-regulation skills through various studies, demonstrating that these skills play an important role in children's early mathematics achievement. Additionally, studies by Palabıyık & Tertemiz (2024) and Louange and Bana (2010) have examined the relationship between number sense and problem-solving skills. However, based on the researchers' review, scientific studies that simultaneously examine

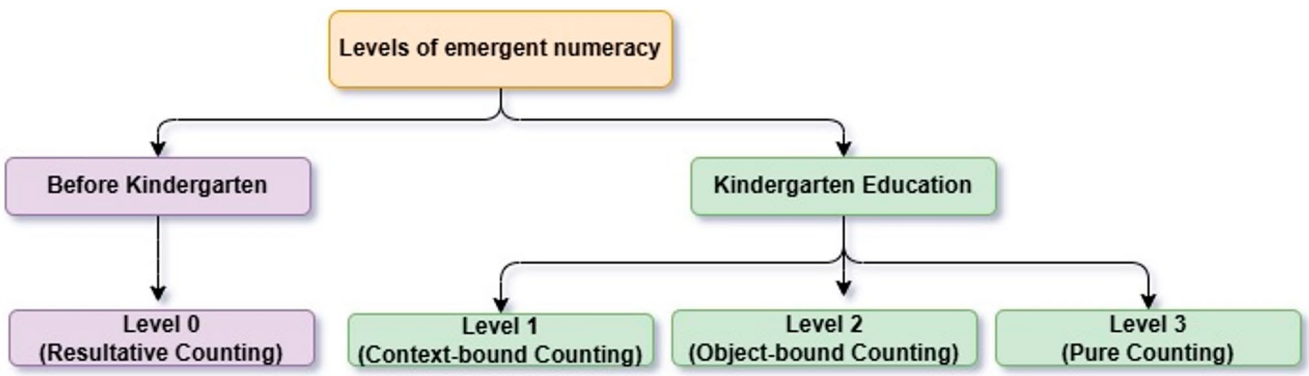


Fig. 1 Realistic Mathematics Education Levels in Kindergarten Education (Van Den Heuvel-Panhuizen, 2008)

number sense, self-regulation, and problem-solving skills together—and identify number sense as a mediating variable between self-regulation and problem-solving skills—have not yet been identified in the literature. Therefore, the fundamental factors contributing to individual differences observed in children's self-regulation and problem-solving skills have not been fully clarified. Moreover, the specific effect of number sense on these skills and its possible mediating role have not been sufficiently examined in the existing literature. Thus, empirical data are needed to clarify these relationships and to support the design of effective educational programs, targeted interventions, and digital tools aimed at fostering these critical skills in early childhood.

This study aims to fill this knowledge gap and improve the quality of early childhood education. A better understanding of the factors affecting the development of self-regulation and problem-solving skills will contribute to improving pedagogical practices that will support children's holistic and sustainable development.

Investigating the relationship of number sense, which forms the basis of mathematics achievement, with self-regulation and problem-solving skills will be an important step in improving the individual's overall mathematics achievement and learning process. Structuring educational programs and teaching strategies accordingly will make it possible to design more effective interventions and more innovative digital applications and educational activities (Gözüm et al., 2024). In this context, by clarifying the mediating role of number sense in the predictive relationship between self-regulation and problem-solving skills in early childhood, the study offers valuable contributions to both scientific understanding and pedagogical practice. For this purpose, the potential mediating role of mathematics-related skills, particularly number sense, between self-regulation and problem solving is discussed with the proposed model and hypotheses.

Proposed model and hypotheses

This study was designed to analyze in depth the relationships among self-regulation, problem solving and number sense, and in particular, it focuses on the role of self-regulation skills in the problem-solving process and whether number sense mediates this relationship. The main hypotheses of the study are:

Figure 2 shows the model of the mediating effect of number sense between self-regulation and problem solving, which the study aims to examine.

Self-regulation and problem solving

Self-regulation is broadly defined as an individual's ability to manage their own behavior, emotions, and thoughts

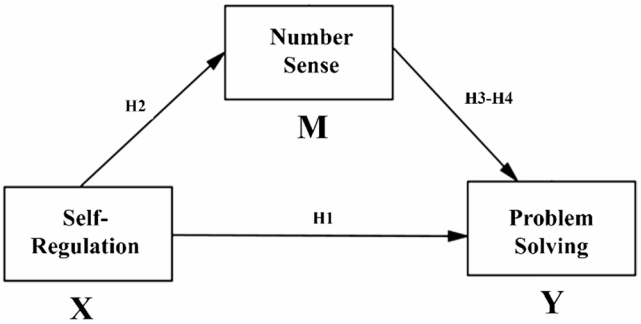


Fig. 2 Mediating effect model and hypotheses

in pursuit of personal goals and in response to situational demands. It encompasses both the capacity to control impulses and guide actions (Baumeister & Vohs, 2007), as well as the multifaceted processes through which individuals regulate their cognitive, emotional, and behavioral functioning to adapt effectively to their environments (Boekaerts & Niemivirta, 2000). Individuals' ability to develop their own strategies acquired through self-regulation and to apply these strategies plays an important role in the development of their problem-solving skills (Zimmerman & Schunk, 2011). It is stated that self-regulation skills have a critical impact on individuals' problem-solving skills. Previous studies have shown that individuals with strong self-regulation skills are better problem solvers (Zimmerman & Campillo, 2003). The development of self-regulation strategies enables individuals to plan, monitor, and adapt their actions, thereby supporting effective problem-solving processes (Zimmerman, 2000). However, the degree to which self-regulation strategies predict performance varies depending on the type of problem and the strategies required for its solution. Nevertheless, numerous studies have reported that the development of self-regulation is positively related to individuals' problem-solving performance (Pintrich, 2000). In this context, the study by Hassinger-Das et al. (2014) investigated how executive functions and attention problems affect first-grade mathematics achievement in children with low number sense during the preschool period. The results showed that both executive functions and attention problems partially mediated the relationship between preschool number sense and mathematics achievement in elementary school. Specifically, attention problems were found to be stronger predictors of mathematical calculation performance, whereas executive functions were more strongly associated with applied problem-solving performance. These findings emphasize the need for comprehensive interventions that not only target number skills but also address executive functions and attention problems to improve the mathematics achievement of children with low number sense. Therefore, supporting executive functions alongside early development of number sense plays

a critical role in enhancing children's mathematics success. In the light of these results, the first hypothesis of the study was determined as *"H1: Self-regulation significantly predicts children's problem-solving skills."*

Self-regulation and number sense

Self-regulation is a multi-faceted and comprehensive concept that enables individuals to manage their emotions, thoughts and behavior (Baumeister & Vohs, 2007; Boekaerts & Niemivirta, 2000). The individual should be aware of the learning process and use his/her self-regulation skills to manage this process (Trautner & Pinquart, 2025). It is stated that individuals with strong self-regulation skills who can manage the learning process well are academically successful, including in mathematics (İvrendi, 2016a). It is known that self-regulation skills are important for developing number sense, which is a critical skill for mathematics achievement (İvrendi, 2011, 2016b). It is stated that self-directed learning activities are very effective in improving number sense skills.

In parallel, Zhang et al. (2023) demonstrated a reciprocal relationship between executive functions—particularly working memory and cognitive flexibility—and mathematics achievement from preschool through elementary school. Their longitudinal findings indicate that working memory and math performance mutually reinforce one another beginning in early childhood, while cognitive flexibility shows similar reciprocal effects from later grades. These associations weaken over time, suggesting that early executive functioning plays a particularly critical role in supporting long-term mathematics development.

Similarly, the study by Chan and Scalise (2022) revealed that executive function skills in children aged 3 to 6 significantly predicted both concurrent and later performance in numeracy tasks such as set counting, numeral identification, number comparison, and number line estimation. Moreover, numeracy skills were found to mediate the relationship between executive functions and mathematics achievement. These findings highlight that the influence of executive functions on mathematical performance in early childhood occurs indirectly through the development of specific numeracy skills. Therefore, supporting each component of numeracy and fostering executive functions are essential for enhancing early mathematical development. Based on this observed positive relationship between self-regulation and number sense, the second hypothesis of the study was formulated as: *'H2: Self-regulation significantly predicts children's number sense.*

Number sense and problem solving

Number sense is an important part of the mathematical thinking process. Number sense is defined as the individual's ability to understand numbers and the relationships between numbers and to develop effective solutions to mathematical problems (McIntosh et al., 2005). Number sense skills help the individual comprehend the quantitative dimension of numbers and visualize concrete examples (Palabıyık & Tertemiz, 2024; Louange & Bana, 2010). Number sense plays a critical role in the processes of understanding mathematical concepts and solving mathematical problems (Jordan et al., 2010), and is one of the prerequisites for the development of an individual's advanced mathematical skills, including problem solving. It is stated that the development of number sense skills in early childhood helps in solving daily life problems as well as problems involving mathematical operations, since number sense supports the development of numerical processing and numerical estimation skills, which are necessary for problem solving (Jordan et al., 2008). It has been observed that children with strong number sense skills develop more effective strategies when solving problems and can use the strategies they have learned more flexibly. The strong predictive relationship between number sense and problem-solving skills has been demonstrated in numerous studies (Palabıyık & Tertemiz, 2024; Louange & Bana, 2010; Jordan et al., 2010). Therefore, the third hypothesis of this study was formulated as: *"H3: Number sense significantly predicts children's problem-solving skills."*

The mediating role of number sense

Self-regulation and number sense are two foundational cognitive abilities that jointly support children's early mathematical performance and problem-solving competence. Self-regulation refers to children's capacity to monitor, control, and direct their thoughts, emotions, and behaviors through processes such as goal setting, attentional control, flexible strategy use, and behavioral inhibition (İvrendi, 2011, 2016a, b). Recent research shows that children with stronger self-regulation are better able to sustain attention, adaptively shift strategies, and remain cognitively engaged during academic tasks, including mathematics (Hautakangas et al., 2022). Executive-function components—particularly inhibition, cognitive flexibility, and working memory—constitute the regulatory foundation upon which self-regulated mathematical reasoning develops (Diamond, 2013).

Number sense, in turn, is conceptualized as an essential domain-specific precursor to mathematical thinking, encompassing foundational competencies related to number, number relations (e.g., magnitude comparison), and number operations that enable children to flexibly represent and manipulate numerical information (Jordan et al., 2022). Studies emphasize that number sense forms the conceptual scaffold for interpreting mathematical structures, selecting

appropriate solution strategies, and evaluating their efficiency during problem-solving processes (Palabıyık & Tertemiz, 2024; Louange & Bana, 2010). Importantly, emerging evidence suggests that self-regulation and number sense may operate through reciprocal and mutually reinforcing pathways. For instance, engagement with numeracy tasks often requires sustained attention, inhibitory control, and strategic flexibility—skills that contribute to the development of self-regulation itself (DeFlorio et al., 2019). Complementarily, Montoya et al. (2025) demonstrated that structured scaffolding of self-regulation skills in early learning environments directly enhances children's mathematical engagement and conceptual understanding by helping them regulate cognitive load and adapt strategies during challenging tasks. Recent studies in early mathematics further support this dynamic interplay. Bernal-Ruiz et al. (2024) showed that cognitive flexibility and planning—two executive subcomponents central to self-regulation—significantly predict both logical-relational and numerical mathematical competencies in early childhood. Likewise, Prager et al. (2023) found that targeted executive-function training improves foundational numeracy skills, demonstrating that EF processes can transfer to number-related domains. These findings reinforce the theoretical view that self-regulation provides essential cognitive control mechanisms through which number sense can be effectively applied during problem solving. The mediational link becomes clearer when considering how children construct mathematical strategies. Number sense facilitates efficient representation of numerical information, recognition of relevant quantities, and flexible selection of solution approaches—all of which are critical for self-regulated problem solving. Supporting this perspective, Ruffini et al. (2024) demonstrated that training embedded in mathematical contexts strengthens executive-function processes by engaging children in reflective, goal-directed reasoning. Similarly, Fuhs et al. (2016) showed that preschoolers' ability to rapidly and holistically identify number sets significantly mediated the relationship between executive functions and early mathematics achievement. This indicates that number sense acts as a cognitive bridge through which general regulatory skills translate into effective mathematical performance. Synthesizing these theoretical and empirical perspectives, number sense appears to play a mediating role by enabling children to coordinate regulatory processes with domain-specific mathematical reasoning. Self-regulation enhances the capacity to engage with numerical concepts, while number sense provides the conceptual tools needed to deploy self-regulatory strategies effectively during mathematical problem solving. Accordingly, the present study proposes the following hypothesis: "*H4: Number sense statistically mediates the predictive relationship between self-regulation and problem-solving skills.*"

Method

The aim of the study is to analyze the accuracy of the model of the mediating effect of number sense between self-regulation and problem solving. To examine this relationship, the research method was determined as the correlational survey design, one of the quantitative research methods. The correlational survey design is a research approach used to understand the relationship between two or more variables and the extent of this relationship. Structural equation modeling (SEM) was selected as the analysis method appropriate for the design and purpose of the study (Kline, 2023).

Participants

The study was conducted with 244 children aged 60–72 months attending public independent kindergartens and preschools in the northeastern anatolia region of Türkiye. The children who were to participate in the study were determined by random sampling, and students whose parents provided consent forms were included in the study. The developmental status of the children was normal and there was no progress report.

Among the children participating in the study, 43% ($n=105$) were girls and 57% ($n=139$) were boys, and 88.4% ($n=215$) of the children had one or more siblings. The family income distribution was 24.9% low income ($n=60$), 59.8% middle income ($n=144$), and 15.3% high income ($n=37$), and the general sample consisted of children from families in the lower-middle income group.

Procedure

After the aim of the study was explained to the parents and teachers, the necessary consent was obtained from the parents of the children who volunteered to participate. Before commencing data collection, ethical approval was obtained from the relevant institutional review board, and official permission was secured from the Provincial Directorate of National Education. Subsequently, consent forms along with demographic information forms were sent to the parents of eligible children, and those who did not provide consent were excluded from the study.

The testing environment was arranged in a quiet, distraction-free room to ensure the children's focus during the individual administration of the Number Sense Test. To reduce anxiety and increase comfort, researchers facilitated an introductory meeting between teachers and children, during which time was also spent with the children in the classroom setting. Each child was then taken individually to the prepared room, where the Number Sense Test was administered by the researcher.

Following the assessment, classroom teachers completed the Self-Regulation Skills Scale and Problem Solving Scale based on their observations of the children. Prior to filling out the data collection forms, the items were reviewed together with the teachers to ensure clarity and comprehensibility. In addition, teachers engaged in a six-week familiarization period with the children before the implementation of the scales. They were asked to keep anecdotal records based on their observations for one week before completing the forms, and then fill out the scales accordingly.

All data were collected and managed by the researchers. The process of obtaining the necessary permissions took approximately two months, while data collection was completed within two months. The teachers' observational data collection took approximately three weeks.

Data collection tools

Personal information form This form, which includes demographic information such as gender, number of siblings, and family income level, was prepared by the researcher to obtain information about the general characteristics of the participating children.

Number sense test The Number Sense Scale used in this study was administered following the procedures and psychometric evidence reported by İvrendi (2011). The Cronbach alpha value of the scale was calculated as 0.85, indicating that the scale is a valid and reliable measurement tool. There are a total of 40 questions on the scale form, including 17 main questions and 23 sub-questions. The main questions consist of components such as number identification, number production, counting, numerical conversations and operations, and number estimation. Explanations regarding the answers given by the children are obtained with the sub-questions. On a binary scoring scale, "correct" answers are scored as "1" and "incorrect" answers are scored as "0". The minimum score that can be obtained from the test is 0, while the maximum score is 35.

Self-Regulation skills scale (Teacher Form) This was created by İvrendi & Erol (2018) to determine the self-regulation skills of 4–6 year-old children. The scale was created by administering it to 20 preschool teachers and 438 children between the ages of 4–6, and the Cronbach alpha value was calculated as 0.94. The scale, which consists of 22 five-point Likert-type questions, includes the subscales "Attention", "Inhibitory Control" and "Working memory".

Problem solving scale This scale was originally developed by Willoughby-Herb and Neisworth and later adapted into Turkish by Kaya et al. (2013). The Cronbach alpha internal consistency coefficient of the scale was calculated as 0.96. The scale is of the 5-point Likert type and includes options ranging from "Strongly Disagree" to "Strongly Agree". The scale, which comprises 25 questions in total, consists of the subscales "Attention", "Memory and Reproduction" and "Problem Solving".

The measurement instruments used in this study differed in their scoring structures, with the number sense test consisting of dichotomously scored items (0–1), whereas the self-regulation and problem-solving scales were based on Likert-type ratings. Such differences in measurement formats are common in early childhood and developmental research (DeMars, 2010; Kline, 2023) and may lead to minor variations in variance structures. Teacher-rated assessments are also frequently used in early childhood studies and provide valuable contextual information about children's behavior in natural classroom settings (Mashburn & Henry, 2004). These considerations were taken into account during the analytical process, and model estimates were interpreted with awareness of the heterogeneous scoring formats (Kline, 2023).

Validity and reliability results of data collection tools

Before proceeding to the analysis, validity and reliability studies were conducted for the data collection tools used. The KR-20 reliability coefficient for the binary scored Number Sense Test was calculated as 0.82. The Cronbach alpha coefficients for the Self-Regulation Skills Scale and Problem Solving Scale were calculated as 0.89 and 0.90, respectively. These obtained values constitute evidence for the reliability of the measurement tools used.

Confirmatory factor analysis (CFA) was performed to assess the construct validity of the measurement tools used. The Number Sense Test was not included in this analysis because it is evaluated based on total scores. Second-order multi-factor CFA was conducted for the Self-Regulation Skills Scale and Problem Solving Scale, each of which contain three subscales. Item factor loadings of the Self-Regulation Skills Scale vary between 0.67 and 0.85.

The second-order confirmatory factor analysis (CFA) results for the Self-Regulation Skills Scale indicate that the proposed model demonstrates an acceptable level of fit. The chi-square to degrees of freedom ratio ($\chi^2/df = 2.72$) falls within an acceptable range, as ratios below 3 are generally considered indicative of adequate model fit in structural equation modeling. The RMSEA value of 0.08 represents the upper boundary of acceptable fit, given that values below 0.06–0.07 are preferred for good fit, while values up to 0.08 are commonly interpreted as acceptable. The GFI value of

0.92 exceeds the minimum threshold for adequacy, although higher values are typically associated with stronger model fit. Incremental fit indices, including TLI (0.92), IFI (0.93), and CFI (0.93), fall slightly below the more stringent criterion of 0.95; however, when evaluated in conjunction with other fit indices, these values indicate an overall acceptable model fit (Kline, 2023).

Item factor loadings for the Problem Solving Scale ranged from 0.63 to 0.85, indicating moderate to strong relationships between the observed indicators and their latent factors. The second-order CFA results further suggest that the model demonstrates an acceptable level of fit. The chi-square to degrees of freedom ratio ($\chi^2/df = 2.75$) falls within an acceptable range for model adequacy. The RMSEA value of 0.07 supports an adequate model fit. The GFI value of 0.91 meets the minimum acceptable threshold, while incremental fit indices, including TLI (0.94), IFI (0.91), and CFI (0.91), although slightly below the optimal cut-off of 0.95, collectively indicate a reasonable and interpretable model fit when considered alongside other indices (Kline, 2023).

Examination of assumptions

Prior to data analysis, preliminary data screening procedures were conducted to evaluate sample size adequacy, missing data patterns, and the assumptions of normality and linearity. Univariate normality was supported, as skewness and kurtosis values for all variables ranged between −1 and +1. Linearity assumptions were examined through visual inspection of scatter plots, which indicated linear relationships among the study variables. In addition, multicollinearity diagnostics showed that tolerance values were greater than zero, variance inflation factor (VIF) values were below 10, and condition index (CI) values did not exceed 30, suggesting the absence of multicollinearity concerns. Taken together, these findings indicate that the dataset met the necessary assumptions for subsequent analyses and was suitable for structural modeling procedures (Kline, 2023).

Analysis method

Mediational structural equation modeling (SEM) was performed with the observed variables to examine whether number sense, proposed as a mediating variable, plays a significant role in the predictive relationship between self-regulation and problem-solving skills, and to evaluate the study's hypotheses. SEM is generally defined as a regression-based framework used to test theoretically specified directional paths among variables, rather than to establish causal relationships (Kline, 2023). This type of analysis aims to determine whether the predictive associations specified in complex models are statistically significant.

In the mediation model proposed in this study (see Fig. 3), self-regulation was specified as the predictor variable (X), number sense as the mediating variable (M), and problem-solving skills as the outcome variable (Y). To statistically test whether number sense (M) transmitted the predictive effect of self-regulation (X) onto problem-solving skills (Y), a structural equation modeling (SEM) framework was employed using maximum likelihood estimation. The mediating path structure was modeled as follows: X → M → Y, where the a-path represents the effect of self-regulation on number sense, the b-path represents the effect of number sense on problem-solving skills, and the c′-path represents the direct effect of self-regulation on problem solving after accounting for the mediator. The total effect (c-path) reflects the combined direct and indirect contributions of self-regulation to problem-solving performance. To evaluate the significance of the indirect effect (a × b), the bootstrap method with 5,000 resamples and a 95% confidence interval (CI) was applied, as the bootstrap procedure yields more reliable estimates than traditional mediation tests (Hayes, 2018). An indirect effect was considered statistically significant if the confidence interval did not include the value 0. This procedure allowed us to determine whether number sense (M) mediated the pathway linking self-regulation (X) to problem-solving skills (Y). Furthermore, mediation type (partial or full) was determined by examining the significance of both the indirect effect (a × b) and the direct effect (c′). If the indirect effect was significant while the direct path remained statistically significant, the model was interpreted as showing partial mediation, indicating that number sense explained part—but not all—of the predictive link between self-regulation and problem-solving skills (Hayes, 2018).

This analytical structure ensured the precise evaluation of the sequential X → M → Y relationships central to the theoretical model of the study.Both the self-regulation and problem-solving scales were completed by teachers, which is a widely used and practical approach in early childhood research. Teacher reports provide ecologically valid insight into children's behaviors in natural classroom contexts (Mashburn & Henry, 2004), although relying on a single informant may introduce some shared-method tendencies (Podsakoff et al., 2003). In addition, the measurement instruments used in this study differed in their scoring structures, with the number sense test consisting of dichotomously scored items (0–1) and the self-regulation and problem-solving measures based on Likert-type ratings. Such differences in scoring formats are common in developmental research (Brown, 2015; DeMars, 2010) and may lead to minor variations in variance structures. These methodological considerations were taken into account during the analytical process, and model estimates were

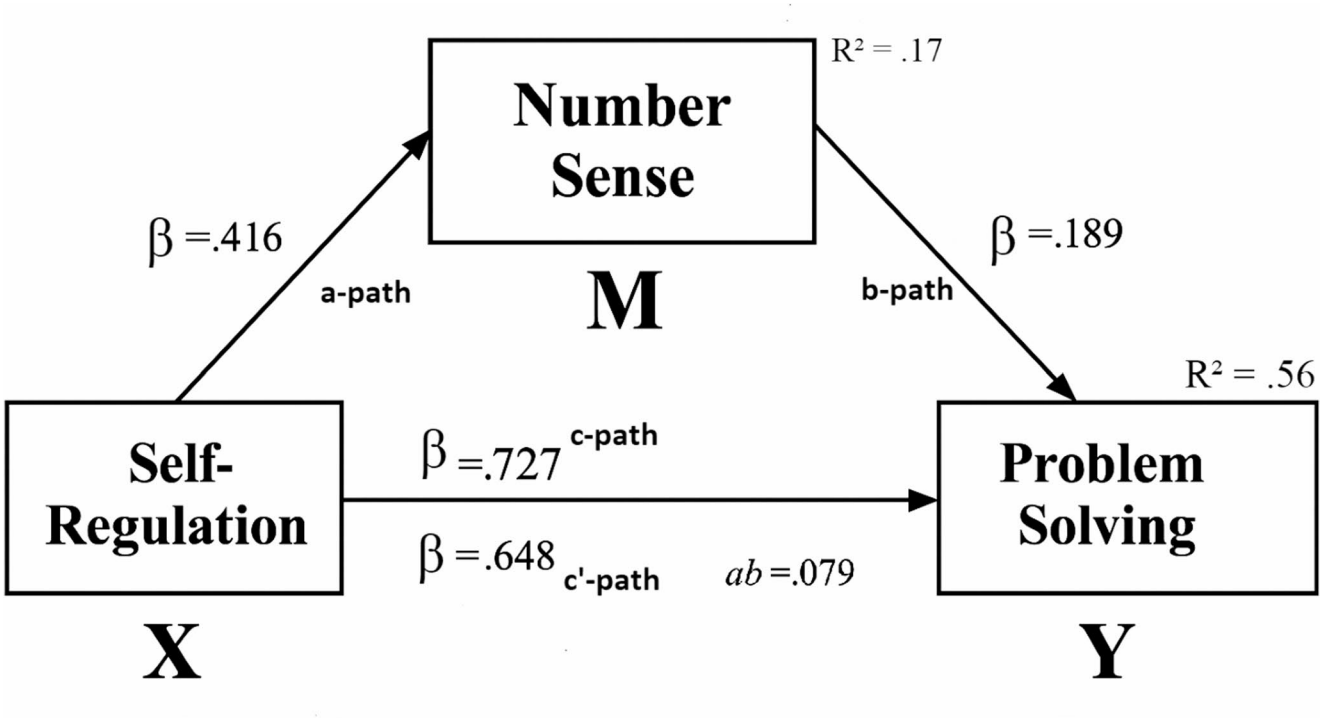


Fig. 3 Standardized path analysis results of theoretical model

interpreted with awareness of the heterogeneous scoring formats (Kline, 2023).

In the findings section, the mediating role is evaluated by first presenting the direct model and subsequently the proposed mediation model. Confirmatory factor analyses and path analyses were performed using AMOS 23, while SPSS 23 was used for data entry, descriptive statistics, and the computation of test statistics and correlation coefficients.

Findings

After examining the normality distributions of the self-regulation, number sense and problem solving variables and the correlations between these variables, the findings regarding the hypothesis tests were analyzed. The skewness and kurtosis values reflecting the normality distribution and the correlation coefficients between the variables are presented in Table 1.

According to the Table 1, significant correlations were found among the variables ($p<.01$). The correlation between self-regulation and number sense is moderate ($r=.416$), while the correlation between self-regulation and problem solving is strong ($r=.727$). The relationship between number sense and problem solving is also moderate ($r=.459$). These results suggest that the impact of self-regulation on problem solving is more pronounced than that of number sense. Additionally, the skewness and kurtosis values for all variables fall between −1 and +1, indicating that the normality assumption is met and supporting the reliability of the analyses. Therefore, the correlations are both statistically significant and based on data that meet distributional assumptions.

As a result of the path analysis performed to ensure standardization of the model with the addition of the mediating variable, the theoretical model presented in Fig. 3 was created.

The values of the path analysis performed to test the hypotheses are given Table 2 below.

According to the path analysis results presented in Table 2, self-regulation shows a significant predictive relationship with problem-solving skills (β = 0.648; CR = 13.822;

Table 1 Correlation between variables and skewness and kurtosis values ($n=244$)

Variable	1	2	3	Mean	Std Dev	Skewness	Kurtosis
1. Self-Regulation	1	0.416**	0.727**	88.34	16.26	0.023	0.366
2. Number Sense		1	0.459**	18.47	5.22	0.378	−0.606
3. Problem Solving			1	94.40	18.26	0.276	0.741

**Correlation is significant at the 0.01 level (2-tailed)

Table 2 Path analysis results

Predictor Variable (X)	→	Outcome Variable (Y)	β	B	S.E.	C.*R.*	*p*	Hypothesis
Self-Regulation (X)	→	Problem Solving (Y)	0.648	0.728	0.053	13.822	0.000	H_1*
Self-Regulation (X)	→	Number Sense (M)	0.416	0.134	0.019	7.129	0.000	H_2*
Number Sense (M)	→	Problem Solving (Y)	0.189	0.661	0.164	4.037	0.000	H_3*

β = Standardized Estimates *B* = Unstandardized Estimates *Supported

p<.01), which shows that hypothesis H_1 is supported. Self-regulation also significantly predicts children's number sense, which supports hypothesis H_2 (β = 0.416; CR = 7.129; *p*<.01). Furthermore, number sense shows a significant predictive association with problem-solving skills, which supports hypothesis H_3 (β = 0.189; CR = 4.037; *p*<.01).

When the contribution of the variables in the model is examined, it can be seen that number sense (R^2 = 0.17) explains 17% of the variance, while problem-solving skills (R^2 = 0.56) explain 56% of the variance (see Fig. 3). "Table 3 presents the results of the path analysis conducted to evaluate the mediating role of number sense in the predictive relationships among the study variables.

As seen in Table 3, the standardized total effect values for the simple effect model, in which number sense was not included as a mediating variable, were analyzed. According to these values, self-regulation was found to have a significant positive predictive relationship with problem-solving skills (β = 0.727; *p*<.01; 95% CI [0.591, 0.889]).

Then, number sense was included in the model as a mediating variable and the results of the mediating effect model were evaluated. In this analysis, the standardized indirect effect results indicate that self-regulation shows a significant positive predictive relationship with problem-solving skills (β = 0.079; *p*<.01; 95% CI [0.040, 0.152]).

Figure 3 illustrates that with the addition of number sense (M), the β coefficient of the effect of self-regulation on problem solving (X→Y; c-path = 0.727) decreased when the mediator was included in the model (c′-path = 0.648). In addition, the upper and lower limits of the bootstrap confidence interval for the indirect effect (a × b = 0.079; 95% CI [0.040, 0.152]) did not include the value '0', demonstrating that both the path from self-regulation to number sense (X→M; a-path = 0.416) and the path from number sense to problem solving (M→Y; b-path = 0.189) were statistically significant. This pattern indicates that the predictive relationship between self-regulation and problem-solving skills is partially accounted for by number sense, as the mediator transmits part—but not all—of the effect from X to Y. Accordingly, the mediation model (X→M→Y) revealed that number sense is a significant mediating variable in this relationship. Furthermore, because the inclusion of number sense did not eliminate the significant direct effect observed in the simple model (c′ remained significant at β = 0.648, *p*<.001), it was concluded that number sense has a partial mediating role rather than full mediation. These findings provide statistical support for Hypothesis H4.

Discussion and conclusion

The present study aimed to examine the relationships among number sense, self-regulation, and problem-solving skills in early childhood and to test whether number sense mediates the relationship between self-regulation and problem-solving. Based on the existing literature, a conceptual model was developed and four hypotheses were tested to better understand factors influencing early mathematical skill development and to inform effective support strategies.

Consistent with the literature, the first hypothesis (H1) was supported, indicating that self-regulation is a significant predictor of children's problem-solving skills (Barrett-Young et al., 2024; Elliott et al., 2022). This finding highlights the importance of integrating self-regulatory processes—such as planning, goal setting, and strategy use—into early educational practices. Learning environments that allow children to explore problems using open-ended materials and self-directed strategies may naturally foster both self-regulation and problem-solving skills. The second hypothesis (H2) was supported, showing that self-regulation

Table 3 Path analysis for the mediating role of number sense

Predictor Variable (X)	Outcome Variable (Y)					Mediating Variable (M)
Self-Regulation (X)	Problem Solving (Y)					Number Sense (M)
	β	*B*	95% CI		*p*	Hypothesis
			Lower	Upper		H_4*
Standardized Total Effect	0.727	0.816	0.591	0.889	0.000	
Standardized Indirect Effect	0.079	0.088	0.040	0.152	0.000	

β = Standardized Estimates *B* = Unstandardized Estimates *Supported

significantly predicts children's number sense, consistent with previous findings (Trautner & Pinquart, 2025; İvrendi, 2016a, b). Self-regulatory processes such as motivation, planning, and process awareness appear to facilitate children's understanding of numerical relationships and the development of flexible processing strategies. Accordingly, integrating self-regulation into early mathematics instruction may support number sense development by encouraging children to verbalize their thinking, plan strategies, and reflect on their solutions.

The third hypothesis (H3) was supported, indicating that number sense is a significant predictor of children's problem-solving skills, consistent with previous research (Jordan et al., 2010; Palabıyık & Tertemiz, 2024). Number sense supports flexible and effective problem-solving by enabling children to interpret mathematical relationships and apply adaptive strategies (McIntosh et al., 2005). Accordingly, educational practices that encourage children to explain their reasoning and engage in mathematical dialogue may strengthen both number sense and problem-solving skills by fostering conceptual understanding and flexible thinking.

Integrating interactive digital applications that offer adaptive number sense activities and gamified problem-solving tasks may further support children's mathematical thinking (Gözüm et al., 2024). By adjusting task difficulty and providing immediate feedback, such tools can enhance engagement, strengthen conceptual understanding, and support the development of independent problem-solving strategies in developmentally appropriate ways.

The fourth hypothesis (H4) was supported, indicating that number sense partially mediates the relationship between self-regulation and problem-solving skills. While self-regulation directly predicts problem-solving, the findings show that number sense accounts for a meaningful portion of this association, highlighting the complex interplay among these constructs in early childhood. Strengthening number sense alongside self-regulation may therefore enhance children's problem-solving abilities by supporting cognitive planning processes rather than reliance on trial-and-error strategies. Consistent with previous research, early number sense development contributes to later arithmetic understanding and more flexible problem-solving through verbal and sequential cognitive processes (Jordan et al., 2007; Okamoto & Case, 1996).

Bodrova & Leong (2005, 2008) stress the importance of kindergarten teachers providing support for all children to improve their self-regulation and problem-solving skills. Therefore, it is recommended to provide children with activities that require following multi-step instructions and that align with the developmental levels of number sense defined by Van Den Heuvel-Panhuizen (2008). Such activities reinforce children's problem-solving processes by supporting their mathematical thinking and number sense development in parallel with their self-regulation skills. For example, following sequential steps in activities such as counting or grouping enhances both attention and systematic problem-solving. The practical theoretical framework for number sense activities highlights the importance of supporting both basic number skills (e.g., counting, number patterns) and conventional arithmetic skills (e.g., story problems) (Jordan et al., 2006, 2007). Basic skills support lower-order number sense (Berch, 2005) and reinforce the concept of quantity discrimination (Okamoto & Case, 1996), thereby preparing children for more complex problem-solving tasks.

As a practical instructional application, teachers may utilize digital whiteboards or tablet-based mathematical storytelling applications that allow children to manipulate visual objects (e.g., apples, blocks, or number lines) while narrating and solving mathematical scenarios. Through open-ended story problems in which children can drag, group, and count objects, teachers can foster flexible thinking, planning, and inner dialogue by posing reflective questions such as "What happens if we take two away?" or "How can we divide this equally?" Such interactive digital storytelling environments not only strengthen children's number sense but also render abstract mathematical relationships more concrete and meaningful within the problem-solving process. As emphasized by Vygotsky, the guided use of language as an intellectual tool enables children to internalize more complex mathematical concepts during problem solving (Uyanık Aktulun et al., 2024). In this context, digital tools can be considered effective instructional resources that support the teacher's scaffolding role in facilitating children's learning processes (Baroody et al., 2012).

The inclusiveness and effectiveness of such digital and play-based applications are of particular importance in the context of this study, which was conducted in eastern Türkiye—a region characterized by predominantly rural conditions and where a substantial proportion of children come from low- to middle-socioeconomic status (SES) backgrounds. According to official income distribution statistics published by the Turkish Statistical Institute (Türkiye İstatistik Kurumu [TÜİK], 2024), provinces in this region, including those in the TRA2 (Northeastern Anatolia) region, remain significantly below the national average in terms of income indicators, reflecting persistent regional socioeconomic disparities. This demographic and socioeconomic context emphasizes two key principles for the design of classroom practices: (I) ensuring that digital learning materials are accessible, low-cost, and designed to include all children regardless of resource constraints (Baroody et al., 2012; Gottschalk & Weise, 2023), and (II) planning targeted support mechanisms for children who may be at risk in terms of mathematical development (Baroody et al., 2012;

Liang et al., 2020). Within this framework, tiered instructional approaches grounded in Van den Heuvel-Panhuizen's (2008) model of number sense development, together with activities differentiated according to children's number sense profiles, offer a promising approach for providing inclusive and effective learning opportunities even in educational settings with limited resources.

Within this theoretical and contextual framework, the present study continues to discuss the mediating role of number sense in the relationship between self-regulation and problem-solving skills through a classroom scenario in which children attempt to divide a pizza equally among five peers. From this perspective, sharing a single pizza among five children aligns closely with early childhood research demonstrating that everyday distribution tasks naturally engage self-regulatory processes and numerical reasoning within meaningful contexts.

Fair-sharing situations require children to sustain attention, plan multi-step actions, and inhibit impulsive responses, all of which rely on the coordinated functioning of working memory, attentional control, and inhibitory control as central components of self-regulation (Baddeley, 2012; Diamond, 2013; Wesarg-Menzel et al., 2023). These regulatory processes shape how children sustain attention, plan actions, and monitor their responses during mathematical activity.

At the same time, equal-sharing tasks provide foundational contexts for the development of number sense and early fractional reasoning. Partitioning a whole into equal parts engages proportional reasoning, estimation, and fairness-based judgments, which are identified as core components of conceptual number sense and early mathematics learning in contemporary developmental frameworks (Jordan et al., 2022; Pittalis et al., 2018). Similarly, partitioning a whole into equal shares encourages children to reason about quantity, equivalence, and spatial relationships, thereby strengthening early mathematical representations that underpin number sense development (Jordan et al., 2022).

These theoretical and empirical findings indicate that everyday equal-sharing situations that emerge spontaneously in daily life can be transformed into powerful instructional tools when pedagogically structured. Hence, natural contexts such as pizza sharing can be discussed not only as opportunities to observe children's existing cognitive processes, but also as meaningful contexts in which self-regulatory demands and numerical reasoning become visible to children.

Response to Intervention (RtI)–based mathematical play aims to respond to children's individual learning needs by integrating play-based learning with graduated instructional support and has been shown to be particularly effective in promoting number sense development among children from low socioeconomic status (SES) backgrounds (Liang et al., 2020; Roos et al., 2023). To systematically leverage such contexts for instruction, the Response to Intervention (RtI) framework can be applied. The classroom scenario in which children attempt to divide a pizza equally among five peers can therefore be systematically structured within an RtI-based mathematical play framework. This framework combines play-based learning with tiered instructional support to address children's diverse learning needs (Liang et al., 2020; Jordan et al., 2022).

Aligned with Van den Heuvel-Panhuizen's (2008) developmental model of number sense (see Fig. 1), children vary in how they coordinate counting, representation, and strategic planning across developmental levels. For example, some children rely primarily on concrete counting actions, whereas others flexibly use mental representations or compare alternative strategies (McIntosh et al., 2005). Importantly, these differences reflect profile-based variability in children's instructional needs—rather than differences in learning goals—as demonstrated by empirically identified number sense profiles (moderate very low, moderate low, moderate high) (Gözüm et al., 2024). Accordingly, this variability manifests in the need for different levels of instructional intervention, ranging from universal whole-class supports (Tier 1; e.g., shared planning prompts or guided discussion), to targeted small-group interventions (Tier 2; e.g., step-by-step visual cues or strategy reminders), and, for some children, intensive individualized interventions (Tier 3; e.g., visual planning supports or teacher-modeled self-talk) designed to sustain goal maintenance and strategic control (Bodrova & Leong, 2005, 2008; Roos et al., 2023). From an RtI perspective, these profile-based differences underscore the need for graduated instructional intervention while maintaining common developmental targets in number sense development (Liang et al., 2020züm et al., 2024).

The heightened demands for abstraction, strategy selection, and self-regulation at this level make individual and contextual differences among children more pronounced. Indeed, Gözüm et al. (2024) reported that household income was associated with children's likelihood of belonging to different number sense profiles. Specifically, children from lower-income households showed a greater tendency to be represented in the moderate very low profile, whereas higher household income was associated with an increased likelihood of membership in the moderate high profile. Rather than indicating deterministic effects, these findings highlight the role of socioeconomic context as a risk-related factor shaping children's learning opportunities.These findings underscore the importance of integrating play-based learning with tiered instructional support, particularly in socioeconomically disadvantaged contexts, and suggest that

everyday life–based activities such as pizza sharing may serve a compensatory pedagogical function by helping to reduce developmental disparities.

Accordingly, when interpreted through both Van den Heuvel-Panhuizen's developmental levels and the RtI-based mathematical play framework, the pizza-sharing scenario serves not merely as a classroom illustration, but as a theoretically grounded, profile-sensitive, and equity-oriented interpretive lens for interpreting how self-regulation and number sense jointly contribute to problem-solving development. This instructional approach has been discussed as a means of illustrating how self-regulation (X) supports children's engagement across increasingly complex numerical contexts, how number sense (M) develops from context-dependent reasoning toward more abstract reasoning, and how these processes jointly contribute to successful problem-solving skills (Y).

However, the purpose of this discussion is to contextualize and interpret the empirical findings of the present study, rather than to claim instructional effectiveness. Therefore, the proposed activity should be regarded as a theoretically grounded illustration, and its educational impact needs to be tested through future experimental and intervention-based research.

Everyday equal-sharing situations, such as the pizza-sharing scenario described above, illustrate how meaningful, experience-based activities can simultaneously activate self-regulation processes and number sense by requiring children to plan, monitor, and adjust their actions. These processes rely on the coordinated functioning of working memory, attentional control, and inhibitory control to maintain task-relevant information and support goal-directed behavior. When integrated with imaginative and rule-based games, such activities foster flexible problem-solving skills and may contribute to reducing developmental disparities associated with socioeconomic inequalities by promoting self-regulation and mathematical thinking within enriched learning environments (Baddeley, 2012; Diamond, 2013; Blair & Raver, 2015). Moreover, the use of digitally enriched number sense activities can expand equality of opportunity by reaching children across diverse living conditions and further strengthening problem-solving skills through adaptive and engaging learning experiences (Gözüm et al., 2024). Overall, the results suggest that self-regulation supports children's problem-solving success largely by strengthening their number sense skills (Fuhs et al., 2016; İvrendi, 2016b), while number sense serves as a foundational building block for more advanced problem-solving abilities in early childhood (McIntosh et al., 2005; Louange & Bana, 2010), underscoring the need for early, targeted interventions that integrate number sense and self-regulation within developmentally appropriate and contextually meaningful practices (Blair & Raver, 2015; Baddeley, 2012; Zimmerman, 2000; Chan & Scalise, 2022).

Recommendations

The findings of this study suggest several implications for future research and practice. Further research may focus on examining the mediating role of number sense in greater depth, particularly through qualitative or intervention-based studies that explore how self-regulation and number sense jointly support problem-solving skills in early childhood.

Importantly, the results highlight the need for early and targeted intervention programs for children at risk in terms of mathematical development, especially those with lower number sense and self-regulation skills. Intervention programs designed for these children should integrate activities that simultaneously support self-regulation, number sense, and problem-solving skills, rather than addressing these domains separately.

The study also underscores the educational value of gamified learning environments, digital games, and technology-integrated activities in early childhood education. Adaptive and play-based digital applications may be particularly effective as intervention tools by providing individualized feedback and additional instructional support for children who require more intensive guidance.

Overall, early identification and intervention focusing on number sense development may contribute to improving children's problem-solving skills and support their long-term academic achievement, particularly for those at risk due to socioeconomic or developmental factors.

Limitations and future research

A key limitation of the present study concerns the demographic and geographical characteristics of the sample. All participants were drawn from a single province located in the eastern region of Türkiye, which is characterized by predominantly rural settlements, limited educational resources, and unique socio-cultural dynamics that differ from those of more urban and socioeconomically diverse regions of the country. Moreover, most of the participating families belonged to lower- and lower-middle socioeconomic backgrounds and held a high school–level education. This restricted regional and socioeconomic composition limits the representativeness of the sample and may reduce the generalizability of the findings to Türkiye's broader and more heterogeneous population.

Nevertheless, this contextual limitation also offers an important contribution. Rural areas and lower-SES

communities are significantly underrepresented in early mathematics and developmental research, both nationally and internationally. By focusing on a rural context, the present study provides rare empirical evidence from an environment where children's educational opportunities, home numeracy experiences, and self-regulatory supports differ substantially from those typically examined in the literature. The fact that the relationships among self-regulation, number sense, and problem-solving skills in this rural sample align with theoretical expectations and prior findings from more advantaged or urban populations suggests that these developmental associations may exhibit a meaningful degree of robustness across sociocultural contexts. This strengthens, rather than weakens, the interpretive value of the findings.

Even so, caution is warranted when generalizing the results. Future studies would benefit from including samples from multiple geographic regions—including metropolitan, suburban, and rural settings—and from a wider range of socioeconomic backgrounds to improve representativeness and ecological validity. Expanding the age range may also help reveal potential developmental changes in the relationships among self-regulation, number sense, and problem-solving skills. Additionally, because this study relied solely on quantitative measures, subsequent research could incorporate qualitative methods (e.g., interviews with teachers and parents) to deepen understanding of contextual factors that shape children's early mathematical and self-regulatory development. Finally, examining additional variables associated with these constructs and conducting longitudinal or intervention-based studies could further clarify how these skills co-develop and influence one another across early childhood. In addition, although the study provides important evidence regarding associations among the variables, it does not permit definitive causal inferences. Future longitudinal or intervention-based studies are needed to clarify the directionality and underlying mechanisms of the relationships identified in the model.

Authors' contributions This study was derived from the first author's master's thesis. The second and third authors served as academic advisors. The first author (Büşra Yaşar Yusumut) designed the study, collected the data, conducted the statistical analyses, and drafted the manuscript. The second author (Ali İbrahim Can Gözüm) provided academic supervision and contributed to the interpretation of the findings and manuscript revision. The third author (Şükrü İlgün) provided academic supervision and contributed to the critical revision of the manuscript. All authors read and approved the final version of the manuscript.

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Data availability The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval This study was approved by the Ethics Committee of Kafkas University, Social and Human Sciences Scientific Research and Publication Ethics Board (Decision No. 65, June 4, 2022). The approval was granted for the master's thesis entitled *"Self-Regulation and Problem Solving in Preschool Children: The Mediating Role of Number Sense"*, conducted by graduate student Büşra Yaşar in the Department of Mathematics and Science Education. All procedures were carried out in accordance with the ethical standards of the institutional and/or national research committee.

Consent to participate Informed consent was obtained from all parents or legal guardians of the participating children prior to data collection. Participation was voluntary, and parents/guardians were informed about the purpose, procedures, and scope of the study.

Consent to publish Parents or legal guardians provided consent for the anonymized data related to themselves and their children to be used for scientific publication purposes. No identifying personal information is included in this manuscript.

Conflict of interest The authors declare that they have no conflict of interest.

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