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Four-to-six-year-olds' developing metacognition and its association with learning outcomes

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Introduction: Metacognition is the ability to monitor and calibrate one's cognitive processes. Prior studies have linked metacognition with learning outcomes; however, very limited research has examined young children's metacognition. This study aims to investigate young children's developing metacognition and its relation to their learning outcomes.

Methods: A total of 74 typically developing children (Mage = 63.69 months) from a state in the Northwestern U.S. participated in this study. This cross-sectional study took place between 2023 and 2024. Metacognition was measured by a validated train track task, where children attempted to assemble two shapes using wooden train track pieces based on plans provided by the research assistants (RAs). This task was video recorded and coded independently by two trained RAs, using an established coding scheme. Children's learning outcomes were measured by the Letter-Word Identification (language) and Applied Problems (mathematics) subsets in the Woodcock and Johnson IV-Achievement assessment.

Results: Results indicated that metacognition improved with age during early childhood, showing a larger increase between ages 5 and 6 compared to ages 4 and 5. Children's metacognition scores did not differ significantly between boys and girls. Regression analysis showed that metacognition scores were significantly related to learning outcomes measured as the sum scores of language and mathematics assessments, controlling for children's age.

Discussion: Our study suggests that children who can effectively monitor and adjust their cognitive processes tend to have better academic outcomes, even at a very young age. Our finding indicates the importance of supporting children's metacognitive skills, alongside traditional academic domains, to enhance overall learning outcomes.

KEYWORDS

young children, metacognition, metacognitive monitoring and control, language, mathematics

1 Introduction

Understanding young children's developing awareness and regulation of cognitive processes (i.e., metacognition; [Nelson and Narens', 1990](#)) may help improve early education experiences and shed light on the early development of metacognition ([Dörr and Perels, 2019](#); [Whitebread and Neale, 2020](#)). Research has shown that metacognition and academic

success are closely related in both adult learners and older children (Avargil et al., 2018; Fleur et al., 2021; Perry et al., 2019). However, little is known about the metacognition of young children (Chen and McDunn, 2022; Roebbers et al., 2020). Recent research findings demonstrate that children as young as 2.5 years old show basic metacognitive abilities such as self-monitoring and adaptive problem-solving strategies (Geurten and Bastin, 2019). Young children's metacognitive abilities transform from intuitive to more intentional cognitive monitoring and control between the ages of 4–6, which is likely driven by their rapidly developing language skills and executive function (Marulis et al., 2020; Papaleontiou-Louca, 2019). Thus, investigating how metacognition develops in early childhood may reveal ways to support children's learning during a developmentally sensitive window (Goupil and Kouider, 2019; Whitebread and Neale, 2020). In the present study, we explore the relationship between young children's developing metacognition and its role in learning outcomes.

Metacognition is defined as the knowledge and regulation of one's cognition (Flavell, 1979). In other words, metacognition is the ability to reflect on our mental activities and adjust cognitive processes in pursuit of goals. In Flavell's (1979) original definition, he proposed two components of metacognition – metacognitive knowledge (i.e., knowledge about the person, tasks, and strategies) and metacognitive regulation/experience (i.e., planning, monitoring, and evaluation). In this study, we adopt Nelson and Narens' (1990) theoretical framing of metacognition, because it provides a cognitive systems perspective that is suited for task-based metacognitive processes such as those examined in the present study. Nelson and Narens' (1990) define metacognition as two dynamic, meta-level processes, which include monitoring and control. While monitoring refers to the assessment of one's cognitive state, control entails altering cognitive processes in response to that assessment. The monitoring process can inform one's cognitive control in real time, therefore enabling strategy and goal adaptation (Nelson and Narens', 1990). Using the metacognition task in this study as an example, children are asked to assemble two shapes (e.g., "O" and "P" shapes) with toy train track pieces according to plans under two randomized conditions, with plans present or absent during the task. In order to achieve the goals, children need to recall/refer to the plan (monitoring) and adjust their construction to match the plan (i.e., control). Children's behavior indicators of metacognition, such as changing train track pieces, are coded to create a metacognition composite score.

Unlike older children who start using explicit metacognitive strategies around the age of 7, young children's metacognition is implicit and closely related to observed behaviors (Whitebread and Neale, 2020). Behavior indicators of young children's metacognition include pausing, experimenting, asking for assistance when faced with a challenging activity, or realizing a mistake (Coughlin et al., 2015). Children's metacognition rapidly advances between the ages of 4 and 6, propelled by general cognitive abilities such as theory of mind (i.e., being able to understand others' mental state), executive function, and language proficiency (Filippi et al., 2020; Gardier and Geurten, 2024). Children begin to exhibit more explicit forms of self-monitoring and control skills by the end of preschool, such as identifying errors and making necessary corrections (Bayard et al., 2021). These developmental changes enable metacognitive processes that are more intentional and introspective, which are essential for learning (Schneider et al., 2022).

Given young children's developmental characteristics, it can be challenging to assess their metacognition. Metacognition can be measured by a variety of tools such as self-reported questionnaires (Craig et al., 2020), think-aloud protocol (Jordano and Touron, 2018), judgment of learning tasks (Roebbers et al., 2021), confidence judgment tasks (Fleming, 2024), and behavior observation (Bryce and Whitebread, 2012). However, because young children have limited language skills, self-reporting and think-aloud approaches are less reliable (Chen and McDunn, 2022). The train track task and the Wedgits task, on the other hand, are developmentally appropriate for capturing young children's metacognitive monitoring and control because they take into account both verbal and non-verbal behaviors during a play-based problem-solving task (Bryce and Whitebread, 2012; Marulis and Nelson, 2021).

The empirical literature on gender differences in metacognitive abilities has yielded mixed findings, and this topic has rarely been explored during early childhood. For instance, Callan et al. (2016) reported that elementary school girls tended to have more advanced self-reported metacognitive strategies related to learning than boys of the same age. In contrast, Lemieux et al. (2019) found that male college students demonstrated more accurate metacognitive judgments of their performance on a spatial navigation task compared to female students. Other research has found no significant gender differences in self-reported metacognition (Merchán Garzón et al., 2020). The conflicting evidence raises questions about whether gender differences are inherent or if they may reflect differences in perceptions of metacognitive ability between boys and girls (Liliana and Lavinia, 2011). Furthermore, assessment context and methods can influence outcomes as well (Gascoine et al., 2017). The possible gender differences in metacognition may also be explained by socialization and cultural expectations, in addition to methodological concerns. For example, teachers and caregivers may unintentionally provide more metacognitive prompts to female students to encourage a more reflective and detail-oriented approach to learning (Acar-Erdol and Akin-Arkan, 2022).

Research has linked metacognition and students' learning outcomes of various ages (Fleur et al., 2021). A meta-analysis of 118 studies on metacognition, intelligence, and academic achievement from preschool children to college students indicates that metacognition is moderately correlated with academic outcomes after controlling for intelligence (Ohtani and Hisasaka, 2018). Similarly, Bryce et al. (2015) found that, compared to executive functions, metacognition correlated more strongly with 5- and 7-year-olds' mathematics and reading achievements. The relation between metacognition and learning outcomes can be understood by the theoretical perspective that metacognition includes both self-regulative and cognitive components (Whitebread and Neale, 2020). Follmer and Sperling (2016) argue that metacognition serves as a mediator between executive function and self-regulated learning (i.e., a cyclical process wherein learners set their learning goals, monitor the process, and reflect on the results), allowing learners to engage their cognitive resources in self-regulated learning more efficiently. Learners can identify mistakes and gaps in their knowledge through the metacognitive monitoring process, and they can modify their learning strategies based on task demands and make plans for future learning through the metacognitive control process (Dörr and Perels, 2019).

Research has revealed several possible mechanisms that metacognition facilitates learning. For instance, children with more advanced metacognition are more likely to recognize errors and modify their learning strategies (Zhao et al., 2019). Metacognition also encourages task perseverance, enabling children to maintain their effort in the face of difficulties (Wang et al., 2021). Further, children with more advanced metacognition abilities are better at avoiding distractions and off-task behaviors, and they also typically establish more challenging learning goals (Leclercq et al., 2023).

Young children rely on learning contexts and adults' and peers' interactions to activate their emerging metacognition skills (Goupil and Kouider, 2019; Zepeda et al., 2019). Research shows that young children tend to have better metacognition and learning outcomes when their caregivers or teachers use metacognitive language (e.g., "Why [a strategy] doesn't work? What else can you do?") or narrate their problem-solving processes (Gardier et al., 2024; Léonard et al., 2023). Moreover, learning tasks that encourage child-directed, open-ended exploration and self-reflection, such as inquiry-based and project-based learning, puzzles, and building activities, can also foster children's metacognition (Fridman et al., 2020). Such social interactions and learning tasks encourage children to think about their actions, adjust strategies, and exercise self- and co-regulated learning (Whitebread and Neale, 2020).

Despite the well-documented link between metacognition and learning outcomes, this topic remains underexplored in early childhood. Metacognitive knowledge has been studied in children as young as 3 years using interviews (Marulis and Nelson, 2021) and tasks that require a judgment of memory or strategy selection (Roebbers et al., 2021). Children's metacognitive regulation has been studied using puzzle tasks and computerized memory tasks that elicit children's metacognitive monitoring and control (Bryce and Whitebread, 2012; O'Leary and Sloutsky, 2017). However, only a small number of these studies adopt an observation method to research young children's metacognitive monitoring and control behavior in an authentic problem-solving context (Bryce and Whitebread, 2012; Buehler and Oeri, 2024; Marulis and Nelson, 2021). Among the limited studies on young children's metacognition and learning outcomes, researchers have examined children's mathematics and literacy outcomes (Desoete and De Craene, 2019; Taouki et al., 2022), but few have used standardized learning outcome measurements, such as those in the present study. Moreover, the developmental window between ages 4 and 6 is much less researched compared to research on metacognition of elementary school children and older populations. Early childhood needs more empirical attention as it represents a critical developmental window where metacognition evolves from implicit self-awareness to more explicit forms of metacognitive monitoring and control (Gardier and Geurten, 2024). Investigating young children's metacognition could inform instructional practices and targeted interventions to support learning. Therefore, the present study aims to explore 4–6-year-olds' developing metacognition and its association with learning outcomes. We ask three research questions:

RQ1. How do children between the ages of 4 and 6 differ in their metacognition?

RQ2. Does metacognition develop differently between boys and girls (controlling for age)?

RQ3. Is metacognition related to children's learning outcomes (controlling for age)?

2 Materials and methods

2.1 Sample

This study was approved by the Institutional Review Board (IRB) at the lead author's university (IRB protocol code 021140). Eligible participants were preschool- and kindergarten-aged children (age = 4–6 years, typically developing) in the surrounding area of the lead author's university from a northwest state in the U.S. Participants were recruited via flyers and social media.

A total of 74 typically developing children ($M_{age} = 63.69$ months). There were slightly more girls than boys ($N_{boy} = 36$, $N_{girl} = 38$). On average, their parents were 37 years old (range = 25–50 years), with 88% having a Bachelor's degree and above. Table 1 shows participants' demographic information. A *post hoc* power analysis showed that our sample size enabled the analysis to reach a statistical power of 0.85 with an alpha of 0.05 and a medium effect size of 0.15 (Cohen, 1992).

2.2 Procedure

This cross-sectional study took place between 2023 and 2024. We used observation and direct assessment methods for data collection. A detailed description of the train track task and the learning outcome assessments can be found in the next section. Upon receiving the children's parental consent forms, trained research assistants (RAs) administered the assessments face-to-face with each child in a university laboratory. Children's verbal assent was also obtained prior to data collection. The RAs introduced the study to each child participant using developmentally appropriate language and asked if they were willing to participate. If the RA failed to obtain the child's verbal assent after three tries, the parents were asked if they would like to withdraw or reschedule. The data collection sessions were divided into two 15–20-min segments with a 5-min break in between to mitigate children's fatigue. The order of the train track task and the learning outcome assessment were randomized for each child. Parents completed surveys in a waiting room adjacent to the laboratory during children's data collection. Upon completion, each child received a toy and book, valued at \$40, as a thank-you for participating. Video data were stored in a password-protected laboratory computer that was not connected to the internet. Paper data were de-identified and entered into an Excel spreadsheet. Identifiable paper data (e.g., demographic survey) were stored in a locked file cabinet in a secure office building.

TABLE 1 Participants' demographic information.

	N	M/%	SD	Min.	Max.
Children					
Child gender					
Male	36	48.60			
Female	38	51.40			
Child age (months)	74	63.69	11.73	48	83
Child race					
White	65	87.8			
African American/black	0	0			
Asian	4	5.40			
American Indian	0	0			
Other	5	6.80			
Child ethnicity					
Hispanic or Latino	2	2.70			
Not Hispanic or Latino	72	97.30			
Parents					
Parent's age	74	37.03	5.80	25	50
Parent's highest education level completed					
High school diploma	1	1.40			
Some college credits but no degree	6	8.10			
Associate's degree	1	1.40			
Additional credits beyond an associate's Degree	1	1.40			
Bachelor degree	23	31.10			
Additional credits beyond a BS/BS	12	16.20			
Master's degree or higher	30	40.50			
Parent's marital status					
Single	4	5.40			
Married	63	85.10			
Divorced	4	5.40			
Widowed	1	1.40			
Separated	2	2.70			
Household income level					
\$10,000 - \$30,000	7	9.50			
\$31,000 - \$60,000	9	12.20			
\$61,000 and above	56	75.70			
Other	2	2.70			

2.3 Measurement

2.3.1 Metacognition

Metacognition was measured by a validated train track task (Bryce and Whitebread, 2012), a developmentally appropriate, play-based construction task designed to elicit children's metacognitive behavior. In the train track task, children were asked to assemble two shapes using wooden train track pieces based on plans provided by the RAs. Each child attempted an

easy shape and a difficult shape (i.e., 48–71-month-old children tried an oval shape [easy] and a goggle shape [difficult]; 72–83-month-old children tried a goggle shape [easy] and a P shape [difficult]). The easy and difficult shapes were randomized under two conditions: plan available, where children could refer to the plan throughout the construction, and plan removal, where the RA removed the plan after showing it to the children, and the children relied on their memory to complete the assembly. Video recordings of this task were coded, using an established, validated coding scheme, independently by two trained RAs using

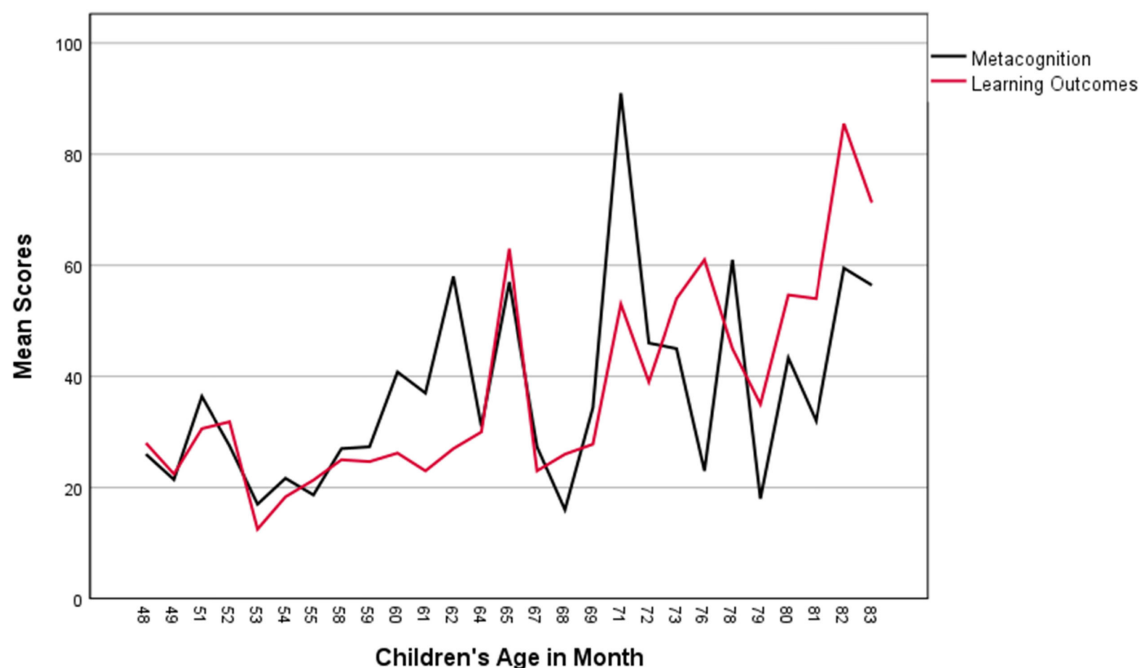


FIGURE 1

Represents children's metacognition scores and learning outcomes by age. The x-axis is children's age in months, ranging from 48 to 83 months (i.e., 4–6 years). The y-axis is the average of children's metacognition and learning outcome scores at each month of age. The red line represents metacognition scores, measured by the train track task. The black line represents learning outcome scores, which are measured as the sum of language and mathematics scores. Four-to-six-year-olds' metacognition and learning outcomes are moderately correlated ($r = 0.46$). Children's metacognition increases more rapidly between 5 and 6 than between 4 and 5.

the software Observer XT. This coding framework included 26 verbal and non-verbal behavior indicators under three categories: (1) Monitoring (e.g., Checking Own [a pause to review whole of own construction, not checking only one area.]), (2) Control (e.g., Change Strategy [using a different strategy or piece than before, not just the first strategy or piece chosen]), and (3) Lack of Monitoring and Control (e.g., Goal Neglect [showing awareness of the rule/error but not acting accordingly]). Each child's metacognition score was calculated by subtracting the Lack of Monitoring and Control scores from the sum of the Monitoring and Control scores. The secondary coder coded 20% of the videos; the inter-rater reliability was satisfactory ($\kappa = 0.76$ – 0.87).

2.3.2 Learning outcomes

Children's learning outcomes were measured by two subsets in the Woodcock and Johnson IV-Achievement assessment ($\alpha = 0.94$). Woodcock and Johnson is a standardized, norm-referenced assessment designed to measure a range of academic skills. We used the Letter-Word Identification subset to assess children's reading proficiency and the Applied Problems subset to assess children's mathematics skills – two foundational academic skills. The Letter-Word Identification subset measures children's reading proficiency, such as their ability to recognize and pronounce words. For example, children were asked to read a list of letters out loud. The Applied Problems subset requires children to analyze and solve practical math problems, tapping into their quantitative reasoning and arithmetic capabilities. For example: "If you have three apples and you buy two more, how many

apples do you have now?" Children's answers were recorded on scoring sheets.

3 Results

We first tested the assumptions for Pearson correlation and multiple regression. The scatterplots of the metacognition scores appeared to be linear, and the residuals were evenly distributed, indicating that the assumptions of linearity and homoscedasticity were met (Schmidt and Finan, 2018). Results of the Shapiro-Wilk test and box plot (Shatz, 2024) indicated that metacognition and learning outcome scores were normally distributed. The variance inflation factors for all variables were within 2, indicating no multicollinearity issue (Thompson et al., 2017). The Durbin-Watson statistics were within the acceptable range (1.5–2.5), suggesting the independence of observations (Garson, 2012). Additionally, there was no missing data in our dataset.

3.1 Research question 1

To answer RQ 1 (How do children between the ages of 4 and 6 differ in their metacognition?), we first conducted a Pearson correlation analysis between children's age (in months) and their metacognition scores. The analysis revealed a moderate and statistically significant positive correlation ($r = 0.46$, $p < 0.01$), indicating that older children tended to have more advanced metacognition. The average metacognition scores were 29.35 for

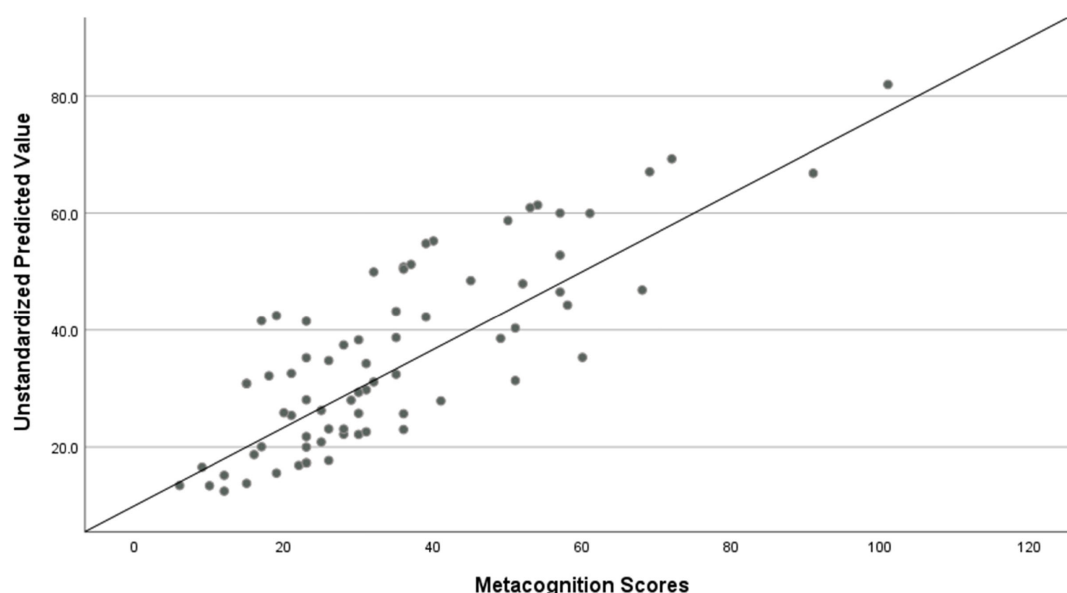


FIGURE 2

Illustrates children's metacognition in relation to their learning outcomes. The x-axis is children's metacognition scores; the y-axis is the unstandardized predicted value when using metacognition as the independent variable, children's age as the covariate, and learning outcome scores as the dependent variable. The model shows a significant association between 4 and 6-year-olds' metacognition and learning outcomes, controlling for age ($\beta = 0.40$). Over half of the variance in learning outcomes is explained by the model ($R^2 = 0.63$).

4-year-olds, 37.14 for 5-year-olds, and 48.56 for 6-year-olds. We then graphed the means of metacognition scores at each month of age to show the developmental trend of children's metacognition. As Figure 1 shows, metacognition scores were trending upward slightly from 4 to 5 years, with an average increase of 7.79 points from age 4 to 5. Children's metacognition began to advance more rapidly between 5 and 6, with an average increase of 11.42 points from ages 5 to 6. Our result suggested, consistent with developmental theories of metacognition, metacognitive abilities appeared to improve as children grow older, particularly in the 5–6 age range, where cognitive and metacognitive skills were fast evolving.

3.2 Research question 2

To answer RQ2 (Does metacognition develop differently between boys and girls [controlling for age]?), we conducted an Analysis of Covariance (ANCOVA) with gender as the independent variable, controlling for age. The results showed, at this early stage of development, metacognition scores of boys and girls did not differ statistically ($p = 0.45$). This finding was consistent with some previous studies indicating gender parity in young children's metacognitive skills (Mohamed, 2012), however, conflict with studies conducted with older ages groups (e.g., Lemieux et al., 2019).

3.3 Research question 3

Finally, to investigate RQ3 (Is metacognition related to children's learning outcomes [controlling for age]?), we conducted

a multiple regression analysis with metacognition scores as the predictor and academic achievement, measured as the sum score of language and mathematics assessments, as the outcome variable. The results indicated that metacognition scores were significantly and positively related to academic performance ($\beta = 0.40$, $p < 0.001$, $R^2 = 0.63$), as illustrated by Figure 2. This finding suggested that children with stronger metacognitive skills also tended to have better learning outcomes. Over half of the variance was accounted for by our model, suggesting that our model had satisfactory explanatory power. This finding was also supported by Figure 1, where the black line represents children's metacognition, and the red line represents their learning outcomes. Both lines increase with age, with a steeper incline after age 5. We also conducted additional analysis with language and mathematics scores as separate outcomes. Results showed that children with more advanced metacognition tended to have better language ($\beta = 0.55$, $p < 0.001$, $R^2 = 0.62$) and mathematics ($\beta = 0.56$, $p < 0.001$, $R^2 = 0.61$) learning outcomes.

4 Discussion

The purpose of this study is to investigate 4–6-year-old children's developing metacognition and its role in their learning outcomes. Our data analysis results revealed a moderate positive correlation between age and metacognition scores, suggesting that metacognitive abilities improve as children grow older, advancing more rapidly between ages 5 and 6. Also, there were no significant differences in metacognition scores between boys and girls during early childhood. Finally, regression analyses demonstrated a moderate association between young children's metacognition and

learning outcomes, with higher metacognition scores predicting better language and mathematics learning achievements.

4.1 Metacognition improves with age

Our results showed that metacognition improves as children become older; this finding was supported by existing literature on young children's cognitive development (Filippi et al., 2020). In particular, we found that children's metacognition development accelerated between the ages of 5 and 6, compared to their metacognition scores between 4 and 5. In line with previous research, our finding suggests a crucial period between the ages of 5 and 6 when children begin to use memory strategies more purposefully to govern their actions in contrast to employing metacognition intuitively (Gardier and Geurten, 2024). This finding might imply that early childhood could be a critical period for fostering metacognition development. Researchers could create instructional strategies and intervention programs catered toward children at this developmental window to support their metacognition and learning. A recent meta-analysis of the effect of metacognitive interventions designed for preschool and elementary school children showed that such programs, especially those delivered by classroom teachers rather than researchers, had a positive impact on children's self-regulated learning – a concept closely related to metacognition (Eberhart et al., 2025).

Previous research suggests that the development of metacognition during early childhood is enabled by children's fast-growing language skills and increasingly complex social environments (Fridman et al., 2020; Whitebread and Neale, 2020). Language serves as an essential tool for representing mental constructs and enables children to be aware and communicate with others about their non-visible internal state, such as cognitive monitoring and control (Ebert et al., 2017; Kälén and Roebbers, 2022). Early childhood is a crucial time for language development, where children make significant progress in their expressive and receptive vocabulary, as well as their understanding of semantics and syntax (Ebert, 2020; Schneider et al., 2022). Further, as children enter preschool around the age of 3 and kindergarten around the age of 5, they experience increasingly complex social interactions and learning environments (Papaleontiou-Louca, 2019). Social exchanges in preschool and kindergarten classrooms afford opportunities for scaffolding from teachers, problem-solving, and peer interactions (Branigan and Donaldson, 2020). These early school experiences likely facilitate the growth of young children's metacognition (Aydin and Dinçer, 2022).

4.2 No gender difference in metacognition during early childhood

Our data analysis results showed no gender differences in 4–6-year-olds' metacognition scores, indicating that metacognition might develop similarly in boys and girls during early childhood. Our finding is supported by other research conducted with young children on their general metacognitive abilities (Mohamed, 2012), but contradicts studies conducted with older age groups using metacognition measurement in specific academic and cognitive

domains (e.g., Lemieux et al., 2019; Merchán Garzón et al., 2020). Gender differences in metacognition tend to appear among older children and adults (Merchán Garzón et al., 2020) and in specific domains, such as reading comprehension (favoring females) (Acar-Erdol and Akin-Arikan, 2022) or spatial reasoning tasks (favoring males) (Lemieux et al., 2019). A possible explanation for our findings regarding gender differences in metacognition is that young children's developing metacognitive skills have not yet been influenced by gendered socialization experiences to the same degree as in later childhood or adulthood (Leaper, 2023). Future studies on this topic could examine a larger population over time using diverse tools to measure metacognition.

4.3 Metacognition is associated with children's learning outcomes

In the current study, 4–6-year-olds' metacognition scores were moderately and positively associated with their learning outcomes, measured as the total score of their language and mathematics assessments. Previous research suggested several mechanisms through which metacognition may support learning. For instance, children with more advanced metacognitive skills tend to be more skilled at setting learning goals, selecting effective strategies, identifying gaps in their understanding, resisting distractions, and persisting when facing challenges (Leclercq et al., 2023; Wang et al., 2021), thereby achieving better learning outcomes (Marantika, 2021). The majority of research linking metacognition to learning outcomes is conducted with older children and adults (e.g., He et al., 2024; Stanton et al., 2021), whereas the findings in our study revealed that metacognition plays an important role in young children's learning outcomes as well.

Previous intervention, observation, and meta-analysis studies have shown that metacognition can be nurtured through direct teaching strategies, learning materials, and teachers' scaffolding. For instance, the “Visible Learning” project (Hattie et al., 2016) focuses on directly teaching K-12 students metacognitive strategies related to mathematics, such as self-questioning and problem-solving. The effect sizes of these strategies range from 0.53 to 0.64. In a study conducted by van Loon et al. (2021), the authors developed a secret code task for second and fourth-graders to deliberately exercise their metacognitive monitoring, control, and judgment. They found that direct teaching of cognitive strategies (e.g., making associations and self-testing) and child-centered instruction (e.g., giving children the autonomy to manage their own learning) predicted more accurate memory monitoring and better task performance. A recent meta-analysis on the effectiveness of metacognition interventions revealed that most of such intervention studies targeted elementary school children, and they showed positive benefits on children's executive functions and learning outcomes across several domains (Eberhart et al., 2025).

Despite the benefits of metacognition interventions on learning, very few were designed for preschool- and kindergarten-aged children (Chen et al., 2024). Many cognitive strategies and tasks in interventions designed for elementary school children, such as setting learning goals and self-reflection, are not developmentally appropriate for young children (Chen and McDunn, 2022). Preschoolers and kindergarteners tend to have

limited language skills and executive function; therefore, it is important to create instructional strategies and interventions that align with their developmental capacities (Perry et al., 2019; Whitebread and Neale, 2020).

4.4 Implications

This study may have several implications for supporting young children's metacognition and learning. For instance, caregivers' and teachers' verbal feedback is a practical approach that is developmentally appropriate for nurturing young children's metacognition (Zepeda et al., 2019). Research has shown that verbal feedback can guide children to articulate and manage their cognitive processes (Urban and Urban, 2021) to bridge the gap in their metacognitive monitoring and control (Goupil and Kouider, 2019). This approach is rooted in research on the anchoring effect – individuals can make decisions or judgments based on a reference point (i.e., an anchor) (Urban and Urban, 2021). In a classroom setting, teachers could use verbal feedback as anchors to shape how children evaluate their learning strategies, consider alternative strategies, and guide children to regulate their own cognition (Urban and Urban, 2018). For example, teachers could prompt children to relate the new information to existing knowledge (e.g., “We are going to learn about a tree's lifecycle today. What do you remember about seeds?”), model reflective questioning during a problem-solving activity (e.g., “Tell me why you do it this way? Do you think it is working?”), and foster children's ability to self-assess and strategically plan (e.g., “How come [a strategy] did not work? What else can you try next time?”).

Aside from verbal feedback, teachers and caregivers could use think-aloud, reflective tasks, and child-directed activities to nurture young children's emerging metacognition. Think-aloud is a teaching technique where the adults model and encourage children to verbalize their thought processes during an activity, which makes mental activities more concrete and explicit (Desoete and De Craene, 2019). Reflective tasks, such as discussing challenges and successes after an activity, could promote children's metacognition regulation (Lewis, 2019). Additionally, child-directed problem-solving activities, such as inquiry-based and project-based learning activities, afford opportunities to enhance children's ability to monitor and regulate their thinking (Chen et al., 2024, 2025; van Loon et al., 2021).

4.5 Strengths and limitations

The first strength of this study is the measurement tools used to assess young children's metacognition and learning outcomes. The train track task is a validated, developmentally appropriate, play-based tool that considers both verbal and non-verbal metacognition indicators. Young children's learning outcomes were directly assessed using the standardized, norm-referenced Woodcock-Johnson IV-Achievement assessment. Secondly, this study contributes to the limited body of empirical literature on young children's metacognition. Our findings on the emerging metacognition of 4–6-year-olds could offer insights into metacognition during a developmentally sensitive period and the early development of self-regulated learning.

This study also has several limitations. First, our sample is restricted to a northwest region in the U.S., where most of the participants were from a rural university town and share similar socio-economic and cultural backgrounds. As a result, our participants were not representative of a larger U.S. population. Generalizations to other communities and cultural groups should be interpreted with caution. The homogeneity of our participants also limited our ability to explore contextual variables' association with metacognition, such as socio-economic status, school attendance, and culture (Branigan and Donaldson, 2020; Papaleontiou-Louca, 2019). Future research could explore these potential associations with a diverse population. Second, this study adopts a cross-sectional design. Thus, the results infer correlations between metacognition and learning outcomes, but the relationship is not causal. Third, although children's age was added as a covariate in the model, we did not measure or control children's executive function. Given the overlap of metacognition and executive function, future research should account for executive function when examining the relationship between metacognition and learning outcomes. Fourth, we measured metacognition in a laboratory, which may not be generalizable in real-world scenarios. Future researchers could consider adding complementary, self-regulated learning measures that pertain to children's behavior in natural classroom settings, such as the teacher-reported Children's Independent Learning Development checklist (Whitebread et al., 2009) and the observer-rated Regulation-Related Skills Measure (McCoy et al., 2017). Fifth, although the train track task is validated and play-based, it mainly captures the behavior manifestation of metacognition and overlooks metacognitive knowledge. Also, the behavior coding process is lengthy and may introduce coders' bias. Children's performance on this task may be subject to their motivation and motor skills. A variation of the train track task using Wedgits (a multi-dimensional building toy) includes a behavior coding scheme and a metacognitive knowledge interview post-task. The metacognition scores are derived from behavior and self-reported evidence, tapping into both metacognitive knowledge and regulation (Marulis and Nelson, 2021). Other complementary measurements of children's metacognition are such as computerized memory tasks (e.g., “Odd ones out” and change detection tasks) with confidence judgment or wagering (Roebbers et al., 2021). Lastly, we did not control for children's school attendance. Given the impact of teacher-child interaction and peer interactions on metacognition (Aydin and Dinçer, 2022), future research should report and control for whether young children attend preschool and kindergarten, as well as the duration of their attendance.

4.6 Future directions

Future researchers could use longitudinal data to track metacognition's developmental trajectory from early childhood to adulthood. Such a study would also provide insight into metacognition developmental milestones and the predictive power of early metacognition development on later academic outcomes. It would also be worthwhile for future researchers to explore task-specific and contextual factors that might impact children's metacognition, such as task difficulty, scaffolding, learning

environment, and social interaction. Additionally, researchers should create and evaluate metacognition interventions that are developmentally appropriate for young children. Considering children's metacognition transforms from implicit to explicit between the ages of 4–6, evidence-based interventions designed for children during this critical developmental window could theoretically have a far-reaching impact on their learning.

5 Conclusion

This study aims to investigate 4–6-year-old children's developing metacognition and its association with their learning outcomes. Our results revealed a significant improvement in deliberate metacognitive monitoring and control between ages 5 and 6, contributing to the literature on age-related changes in metacognition. The absence of gender difference in metacognition suggests that metacognition may develop similarly for boys and girls at this stage. Further, our results indicate that metacognition is moderately associated with learning outcomes – a phenomenon that is well-documented in older children and adults but lacks empirical support in young children. Our study highlights the importance of metacognition in learning and the potential to nurture young children's metacognition during a critical period of development. However, the majority of current metacognition interventions are created for elementary school children and are not developmentally appropriate for preschool and kindergarten-aged children. Future researchers should explore how instructional strategies, task demands, and learning environments impact metacognition during early childhood and examine the long-term impact of metacognition on learning outcomes, adaptability, and academic success later in life.

Data availability statement

The unidentified data can be made available upon request to the corresponding author.

Ethics statement

The studies involving humans were approved by Institutional review board, University of Idaho. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

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SC: Validation, Methodology, Data curation, Visualization, Supervision, Conceptualization, Project administration, Software, Investigation, Resources, Formal analysis, Writing – original draft, Writing – review & editing. MG: Methodology, Investigation, Writing – review & editing, Writing – original draft, Data curation. KH: Supervision, Project administration, Data curation, Investigation, Writing – review & editing.

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