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Metacognitive Limitations in Young Learners: Assessing Barriers to Awareness and Problem-Solving in Third-Grade Students

Sepideh Norouzi[1]✉, Samaneh.S Musavian[2], Abdolsaeed Mohammad Shafiee [3], Abbas Taghizade[4], and Sima Jafarikhah[5]

1. *Corresponding Author*, Department of Educational Sciences, Farhangian University, Tehran, Iran. E-mail: sepideh.b.noruzi@cfu.ac.ir
2. Department of Educational Sciences, Farhangian University, Tehran, Iran. E-mail: s.musavian@cfu.ac.ir
3. Department of Educational Sciences, Farhangian University, Tehran, Iran. E-mail: shafiei@cfu.ac.ir
4. Department of Educational Sciences, Farhangian University, Tehran, Iran. E-mail: a.taghizade@cfu.ac.ir
5. Department of Computer Science, University of North Carolina Wilmington, USA. E-mail: jafarikhaht@uncw.edu

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ABSTRACT

Objective: This study explored the metacognitive abilities of students with high working memory capacity in the context of solving mathematical problems.

Method: This study adopted dominant mixed-methods design with quantitative approach and utilized structured interviews alongside standardized assessments. However, developmental constraints limited the explanatory power of the qualitative insights. The measuring instruments included two researcher-developed tests to assess students' mathematics achievement and metacognition levels, a structured interview, and the Working memory index from the Wechsler Intelligence Scale for Children (WISC-IV). The face and content validity of the researcher-developed instruments were confirmed by a panel of 12 experts. Reliability was established using the test-retest method, yielding Pearson correlation coefficients of $r = .87$ for the mathematics test and $r = .85$ for the metacognition assessment. Using cluster random sampling, three female public schools—one from each of three randomly selected districts in Tehran—were chosen. All third grade students in the selected schools (n=262) were assessed, and 31 were purposively chosen based on working memory and math scores (WISC-IV >110, Mathematics Test >7/10). Quantitative data were analyzed using descriptive statistics aligned with the nominal scaling of metacognitive performance, while qualitative interviews underwent directed content analysis.

Results: Data analysis indicated that the students rarely engaged in conscious retrieval of prior knowledge during problem-solving. 90.3% (n=28) never engaged in reflective questioning. While practice was the most cited factor in their success (54.8%), essential metacognitive strategies such as error checking, time management, and self-monitoring were entirely absent from students' reported behaviors. 61.3% (n=19) demonstrated zero strategic effort with unfamiliar tasks, and 54.8% (n=17) prioritized imitative practice over adaptive strategies.

Conclusions: These findings suggest a predominant reliance on automatic, habitual strategies rather than deliberate, goal-directed engagement with the problem-solving process. Also, the study highlights a significance gap between cognitive capacity and metacognitive strategy use in high-working-memory students. To address this imbalance, curricula should incorporate explicit metacognitive training, including guided strategy-transfer exercises, problem classification activities, and structured reflection protocols.

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Introduction

Metacognition refers to an individual's ability to recognize and monitor their cognitive processes (Flavell, 1979). This concept encompasses awareness of mental strengths and weaknesses, planning, monitoring, and adjusting strategies during problem-solving or learning. In other words, metacognition entails "thinking about thinking" and thus plays a critical role in decision-making and problem-solving. Several researchers conceptualize metacognition through its dual components of *knowledge about cognition* and *control of cognition* (Tezer, 2024). In the present study, the two dimensions of metacognitive knowledge and cognitive regulation proposed by Garofalo and Lester (1985) are adopted as the core components of metacognition.

Metacognitive knowledge refers to an individual's understanding of their cognitive processes, enabling learners to comprehend, monitor, and evaluate conceptual and procedural knowledge within a domain (Yerdelen & Sungur, 2019). Cognitive regulation comprises a set of executive processes that allow students to predict, control, plan, and assess their learning and performance (Chen & McDunn, 2022). As with any psychological construct, metacognition is influenced by various factors. Age is among the first identified influencing factors (Bryce & Whitebread, 2012). Forsberg et al. (2021) established that higher-order cognitive activities are mediated by working memory capacity, which itself develops with age. Over time, metacognitive awareness, the ability to control and regulate one's own mental processes, the capacity to identify appropriate strategies for given situations, and decision-making skills reach advanced levels by third and fourth grades (Akaydin et al., 2020). Roebers et al. (2009) demonstrated that while 9-year-olds possess developed monitoring skills, they exhibit less ability to control their problem-solving processes compared to 11-12-year-old students.

Beyond age, other components also affect metacognitive skills. (1) urban/rural environmental factors (Bakkaloglu, 2020); (2) exposure to strategic questioning (Chatzipanteli et al.,2024); (3) individual differences in processing, application, and internalization of these competencies (Azevedo, 2020); (4) working memory capacity (Gardier & Geurten, 2024); and (5) cultural and social interactions (Van der Plas et al., 2022). In recent years, metacognition has been considered an educational necessity (Widiana et al., 2024). Metacognitive abilities lead to notable individual differences in children when they enter school, and these gaps tend to widen further after schooling begins (Whitebread, 2021). It is strong predictors of executive functions and motivation, positively influencing student achievement (Palladino et al., 2025). Students with well-developed metacognitive skills employ more effective strategies, mathematical representations, and logical reasoning when solving problems (Güner & Erbay, 2021). Additionally, Escolano-Pérez et al. (2019) found that only preschoolers who could apply metacognitive skills were capable of independently engaging in problem-solving tasks. Metacognition serves as a critical component that significantly affects both the outcomes and cognitive efforts in problem-solving (Chen & McDunn, 2022). Students with strong metacognitive skills demonstrate: (1) Superior situation awareness in learning contexts; (2) More strategic decision-making in selecting approaches; and (3) Cognitive self-regulation to monitor and adjust their processes (Silver et al., 2023). Fahrni et al. (2025) posited that metacognitive capabilities play a pivotal role in cognitive development itself. Many researchers consider attributing students' failures primarily to deficiencies in cognitive monitoring and executive control (Bal & Doğanay, 2022). Students with high metacognitive skills internalize problems, activate prior knowledge, persist strategically, and critically monitor their thinking (Bal & Doganay, 2022). Overall, extensive research highlights the role of metacognition in students' learning and their performance in problem-solving tasks. In recent years, metacognition has been recognized as a critical element in mathematics education (Hausman et al., 2021; Pennequin et al., 2020). Studies have pointed out the potential impact of metacognition in enhancing mathematical performance (Robson, 2016).

Despite existing theories on the lifelong development of metacognition, many issues—such as precisely identifying the developmental stages of metacognition in children—remain unclear (Roebers & Spiess, 2017). This ambiguity presents challenges in designing evidence-based educational programs for various age groups. Moreover, neuropsychological research related to metacognition tends to focus on highly specific metacognitive processes (Rahnev & Fleming, 2019), and as emphasized by Azevedo (2020), the lack of cross-cultural frameworks has limited the applicability of global findings to Iran's context. Contrary to the findings of Bakkaloglu (2020), Safari and Marzoghi (2011) conducted a study on Iranian students in grades 6, 7, and 8 and found that metacognitive awareness did not vary by grade level, although differences were observed based on gender and educational districts. These inconsistencies reveal the necessity of context-sensitive and developmentally focused research in Iran.

Several valuable domestic studies have been conducted in the field. For instance, Jooyani et al. (2021) showed that metacognitive training improves learning among tenth-grade students; Ghasemizad et al. (2019) found that metacognition is a predictive factor for self-efficacy and critical thinking in graduate students; and Aghdar et al. (2020) identified metacognition as a mediator between executive functions and self-regulated academic learning in university students. However, two key gaps remain. First, there is a lack of valid assessment tools for measuring metacognition among Iranian elementary school students, especially in subject-specific domains. Second, there is limited developmental understanding of metacognition in sensitive grades such as third grade, which serves as a cornerstone for problem-solving skills in international assessments like TIMSS.

Studies such as Roebers et al. (2009) have demonstrated that by the age of 9–10 (approximately equivalent to third grade in the Iranian educational system), children's cognitive monitoring and evaluation skills reach a level where they can review and adjust their problem-solving strategies during task performance. Although full cognitive control is still developing at this stage, third grade represents a critical milestone in metacognitive development. Children of this age begin to transcend intuitive thinking and enter a phase where cognitive monitoring and planning become meaningfully measurable and amenable to educational intervention (Van der Plas et al., 2022). Targeted educational interventions, during this phase, can play a pivotal role in enhancing students' cognitive awareness and academic achievement. Moreover, selecting third-grade students for investigation holds particular significance, as this grade marks a transition within Iran's curriculum toward more abstract mathematical reasoning and advanced problem-solving—skills that are strongly emphasized in international assessments such as TIMSS (Mullis et al., 2020). Research indicates that disparities in metacognitive and cognitive regulation skills at this juncture can be predictive of future performance differences among students (Whitebread, 2021).

As several researchers have argued, metacognition is dependent on working memory (Izzati & Mahmudi, 2018; Tsalas et al., 2017). Additionally, working memory is a predictive component of problem-solving (Zhengm Swanson, and Marcoulides, 2011). Furthermore, students' mathematical knowledge and skills influence their performance. This study was conducted with students exhibiting high working memory capacity and strong mathematical ability. Moreover, this study offers two key contributions: Theoretically, it validates and adapts the metacognitive framework of Garofalo and Lester (1985) within the unique socio-educational context of Iran—and addresses critical gaps in cross-cultural developmental models (Azzedo, 2020; Roebers & Spiess, 2017). Practically, by identifying precise barriers in metacognitive knowledge and regulation among high-potential third-grade students, it provides actionable insights for designing culturally responsive interventions (e.g., teacher training protocols, metacognitive scaffolding in mathematics curricula) aimed at reducing Iran's persistent underperformance on the TIMSS exam. Most importantly, isolating influencing factors on metacognition such as working memory ensures that the diagnosed deficits directly inform targeted educational reforms.

Given the aforementioned evidence, we may hypothesize that deficiencies in metacognitive capabilities constitute one influential factor affecting Iranian students' performance in the TIMSS international assessment, particularly in mathematics (Mullis et al., 2012, 2020; Von Davier et al., 2024). Accepting this hypothesis necessitates curricular interventions to enhance Iranian students' metacognitive competencies. As noted, metacognitive knowledge and awareness of cognitive strengths/weaknesses prove essential for academic success. Developing these critical skills requires systematic planning and training (Lee et al., 2025), though such efforts must be preceded by comprehensive assessment of students' current metacognitive levels. Effective intervention requires initial diagnostic assessment of students' metacognitive capacities, enabling targeted programming.

These findings underscore the critical need for educational interventions and research that both assess children's metacognitive levels and propose strategies to strengthen these capacities during early developmental stages. Such investigations could significantly enhance students' self-awareness and academic achievement. While these insights are valuable, their direct applicability to the Iranian context requires careful examination through cross-cultural validation with local studies. Hence, this research aimed to diagnostically assess metacognitive knowledge and cognitive regulation among high-working-memory Iranian third-grade students during mathematical problem-solving, using Garofalo and Lester's (1985) framework, to identify actionable intervention points for improving TIMSS performance. To this end, the following questions were posed:

1. To what extent do third-grade students demonstrate metacognitive awareness in recognizing and retrieving similar problems during problem-solving?
2. How do third-grade students utilize and manage their prior knowledge in novel situations?
3. Which metacognitive components they perceive as influential in problem-solving?

Materials and Methods

Design of the Study

This study using a descriptive-analytical design within a quantitatively dominant mixed-methods framework. Participants were selected based on predefined criteria, including high working memory capacity and strong problem-solving abilities. Metacognitive variables were assessed through researcher-developed standardized tests and structured interviews. While the primary focus was on quantitative analysis, qualitative data from interviews provided complementary insights, although the depth of interpretation was limited by the participants' developmental stage. This multi-instrument approach enhanced the precision of the evaluation and increased the validity and robustness of the findings by addressing the limitations of single-method assessments. In line with the existing literature (Marulis et al., 2016), relying on a single method is insufficient for capturing young learners' covert metacognitive processes. Therefore, a combination of performance-based tasks and verbal self-report data was employed to enhance validity and provide a multifaceted understanding of metacognitive function.

Study Design and Research Process

This study was conducted in two sequential phases incorporating both quantitative and qualitative data collection.

Quantitative Phase

In the first phase, participant selection was based on predetermined cognitive criteria to control for confounding variables in metacognitive assessment. From an initial pool of 262 third-grade students, 31 participants were selected based on two standardized measures: (1) The Wechsler Working Memory Index (score >110), and (2) a researcher-developed mathematics proficiency test (score >7). Participant selection targeted the upper quartile of the cohort to control for cognitive confounds. This threshold ensured participants possessed sufficient cognitive capacity and domain knowledge to isolate metacognitive barriers from skill deficits, aligning with high-achiever sampling designs in educational cognition research (Veenman, 2011). In the second phase, students completed a standardized metacognitive assessment that included mathematical problem-solving. Given the descriptive nature of the research questions and the nominal scale used to classify metacognitive performance, the data analysis was conducted exclusively using descriptive statistical methods.

Qualitative Phase

To supplement the quantitative data, structured clinical interviews were conducted with all selected participants. The interviews explored students' awareness of problem familiarity, strategic reasoning, and monitoring behaviors. Given the participants' age (9 years old), responses were typically brief and concrete. As a result, the qualitative analysis remained at a descriptive level, focusing on response frequencies rather than interpretive or thematic coding.

Given the developmental limitations of the third-grade participants, phenomenological or deeply introspective methods were deemed methodologically inappropriate for qualitative data analysis. At this age, children possess emerging metacognitive awareness with limited verbal expression skills (Veenman & Spaans, 2005), and they exhibit high susceptibility to suggestion when describing internal states (Saywitz et al., 2017). Therefore, directed content analysis was employed for analyzing the qualitative data. This approach maintains developmental validity and reveals latent metacognition through: (a) observable problem-solving behaviors; (b) verbal descriptions of strategies; and (c) error-monitoring patterns in mathematics tasks (Kibiswa, 2019).

Qualitative interview data underwent directed content analysis using MAXQDA 26. Guided by Garofalo and Lester metacognitive framework, we employed a hybrid coding approach:

- **Deductive phase**: Predefined codes based on theoretical constructs;
- **Inductive phase**: Emergent codes for unanticipated behaviors;
- **Validation**: Inter-coder reliability (κ=0.79) established with two independent raters. This dual-phase process maintained developmental appropriateness while ensuring systematic data reduction.

Population and Sample

The population consisted of third-grade female students in public schools in Tehran. Sampling was carried out in three stages: In the first stage, using random cluster sampling, three districts (districts 2, 6, and 11) were randomly selected from the 22 educational regions in Tehran. In the second stage, one female public school was randomly selected from each of the three districts. All third-grade classes in these schools were included, and preliminary assessments were administered to all students. Due to cultural considerations all sampled schools were girls' institutions. In the third stage, using purposive sampling, 31 students were selected based on specific criteria: a score above 110 on the Wechsler Working Memory Index and a score above 7 on the mathematics proficiency test.

Instruments

Mathematics Problem-Solving and Working Memory Test

The researcher-made mathematics test consisted of 10 questions across three domains designed to assess students' problem-solving skills, developed based on literature related to problem-solving and its components (Gathercole et al., 2006; Godino et al., 2010; Goldin, 1998; Hjalmarson & Salkind, 2007; Phonapichat et al., 2014; Schoenfeld, 1985, Woleck, 2001; Zheng et al., 2011).The assessment evaluated students' proficiency in several key areas: comprehension of the problem statement, identification of pertinent information for problem resolution, recognition of the problem's objective, and the application of diagrams both as a representational aid and as a problem-solving technique. In the scoring process, each correct answer was assigned one point, and each incorrect answer received zero point.

In this study, the localized version of the Working Memory Index of the Wechsler Intelligence Scale for Children (WISC-IV, 2003) was used to assess the participants' working memory. This standardized test consists of five subscales, one of which measures working memory and includes Digit span and arithmetic. It has been standardized for Iranian students by Abedi et al. (2015). The localized version demonstrated validity and reliability. The reliability coefficients was .82.

Metacognition Assessment

The researcher-developed assessment instrument comprised three structured questions sharing a common objective, with each question containing three components:

1. **Problem-Solving Task:** Students were presented with a mathematical problem to solve.
2. **Familiarity Check:** Students were asked to indicate (yes/no) whether they recognized similar problems.

3. **Problem Generation:** If answering "yes" to the familiarity check, students were required to construct an analogous problem.

Problems were selected to ensure students had access to prerequisite strategies and knowledge; practice set of similar problems was administered prior to the main assessment; two structurally distinct "distractor" problems were interspersed to prevent rote application of prior strategies. Students received one point for each correct answer and 0 point for each incorrect answer in the first part of each question. The maximum score for this test was 3. After completing the test, all students were interviewed individually.

Structured Interview

To gain deeper insights into students' cognitive processes, problem-solving strategies, and reasoning patterns, structured interviews were conducted to collect data for later interventions. The interview questions included:

1. Problem-Solving Approach: *When you encounter a new problem, what steps do you take? What do you do when you're unable to solve a problem? / What do you do if your solution doesn't work?*
2. Metacognitive Awareness: *Do you ask yourself whether you've seen similar problems before? How do you know whether you've seen a similar problem before or not?*
3. Strategy Identification: *What helps you solve problems more effectively? What makes some children able to solve problems while others are not?*

The interview framework was developed to align Garofalo and Lester (1985) foundational metacognitive framework, specifically targeting both knowledge of cognition and regulation of cognition. Furthermore, this qualitative component serves to triangulate with the study's quantitative measures, enhancing methodological rigor through multi-modal data integration as recommended by Veenman (2013) for comprehensive metacognition assessment. This dual-focus design enables richer interpretation of how students' self-reported strategies correspond to their actual performance metrics. Following the selection of questions based on theoretical foundations, the initial draft was reviewed and revised within a focus group comprising one curriculum specialist, one educational technologist, one developmental psychologist, one mathematics education expert, and two third-grade teachers. In the subsequent phase, the questions were administered to three students from the experimental group for the purpose of psychometric validation, aiming to identify simplified vocabulary and potential issues within the items.

Validity Reliability, and Ethical Considerations

The measurement instruments underwent rigorous validation, with both face and content validity assessed by a panel of 12 experts comprising mathematics teachers, elementary educators, mathematics instructors, instructional designers, and curriculum specialists. Reliability was established through test-retest method using Pearson correlation coefficients. When administered to 33 students, the instruments demonstrated high reliability, with Pearson's r values of .87 for the mathematics test and .85 for the metacognition assessment, indicating excellent measurement consistency.

Ethical protocols were strictly followed, including obtaining necessary approvals from: (1) The Security Department of Tehran Province's Ministry of Education; (2) Relevant district and school authorities; and (3) Written informed consent from all parents/guardians. This comprehensive approach ensured both methodological rigor and ethical compliance throughout the research process.

Results

Descriptive statistics

Initial assessment of working memory (WISC-IV) and mathematical problem-solving abilities across the full cohort (N = 262) informed participant selection. Descriptive statistics for these measures are presented in Table 1 (M = 104.79, SD = 14.43 for working memory; M = 4.39, SD = 2.21 for mathematics).

Table 1. Descriptive Statistics

	N	Min	Max	Mean	SD
Active memory score	262	72	138	100.96	14.426
Mathtest	262	0	10	4.39	2.208
Valid N (listwise)	262				
Missing	23				

Students' performance in Metacognitive test

Testing students' performance on the Metacognitive test revealed that none of them were able to answer more than one question (n=31, M=.26, SD=.45). Table 2 shows the percentages of students' performance.

Table 2. Students' Performance at Metacognition Test

Students' performance	Frequency	Percent
Could solve just one problem, but could not remember any similar question for the problem	2	6.44%
Could solve one problem and could remember a similar question for the problem	1	3.22%
Could not solve any problem and could not remember any similar question for them	28	90.32%
Could not solve the problem, but could remember a similar question for one problem	0	0%

As shown in Table 2, 90.32% of students could not answer any questions or recall a similar prior question. 6.44% of students, despite successfully solving the problem, reported that they did not remember encountering a similar question before. Overall, only 3.22% of participants were able to recall and write down a question similar to the one provided.

What do students do when they see a problem?

Based on the conducted interviews with the students, nineteen students had no special effort or activity. One of them admitted, "*In this situation, I would be stressful so I couldn't do anything.*" Nine students reported, "*Reading the issue again and paying careful attention to the data of the problem*". Two students said, "*They were going to seek help and assistance from their teacher or parents*". One student said, "*She would imagine her teacher sitting next to her and they would solve it together*". Analysis of student interviews revealed distinct behavioral patterns when confronted with novel mathematical problems that is shown in table 3.

Table 3. Behavioral Patterns and Metacognitive Characteristics during Novel Problem-Solving

Reaction category	N (%)	Metacognitive Level	Key Cognitive Features
Non-Engagement	19 (61.3%)	Absent	• No solution attempts • Zero strategy deployment
Rereading Focus	9 (29%)	Basic Awareness	• Text re-analysis • Data verification
External Help-Seeking	2 (6.5%)	Emergent Regulation	• Teacher/parent reliance • Limited self-initiation
Imaginary Scaffolding	1 (3.2%)	Advanced Simulation	• Mental modeling • Collaborative self-dialogue

The majority (61.3%, n=19) demonstrated no strategic engagement when confronted with unfamiliar problems, while 29% (n=9) employed rereading strategies to carefully analyze problem data. A smaller subset relied on external support, with 6.5% (n=2) seeking teacher/parent assistance and 3.2% (n=1) utilizing imaginary teacher collaboration as a cognitive scaffold.

Students' Metacognitive Awareness of Problem Familiarity

Twenty-eight students reported that they never asked themselves this question and believed that they would know it instantly if they were familiar with the same questions. Two students said, "rarely". and one student said that I did it sometimes. Most students said that the answer would come to their mind at first sight if they could solve the problem. The frequency of each statement is displayed in table 4.

Table 4. Metacognitive Awareness of Problem Familiarity and Associated Cognitive Beliefs

Students'	N (%)	Cognitive Belief about Familiarity	Metacognitive

statement			Significance
Never	28 (90.3%)	"Familiar problems should be instantly recognizable"	Absence of deliberate monitoring
Sometimes	1 (6.5%)	"Sometimes I notice similarities if I think hard"	Nascent strategic awareness
Seldom	2 (3.2%)	"Rarely check unless teacher reminds me"	Teacher-dependent regulation

Which factors do students consider most effective in problem-solving?

Our analysis of interview data revealed ten distinct factors students believe contribute to successful problem-solving, with striking variations in their perceived importance:

Dominant Factor - Practice (n=17, 54.8%):

This element emerged as the most frequently cited component, reflecting students' recognition of procedural fluency.

Secondary Factors:

- Careful Reading (n=9, 29.0%). It demonstrates emerging metacognitive awareness and supports the "reading-to-understand" paradigm.
- Attentive Listening (n=5, 16.1%). It highlights teacher-centered learning perceptions.
- External Help-Seeking (n=4, 12.9%). It indicates social learning orientation.

Rarely Mentioned Factors (<10%):

Factors such as intelligence, motivation, organization, prior knowledge, conducting research, and rereading were rarely mentioned in the studies (in less than 10% of the cases).

Notable Absences:

Notably, there were no mentions of strategy selection, error analysis, self-monitoring, or time management among the students' response.

Discussion

The present study aimed to investigate three core questions regarding Iranian third-grade female students: (1) to what extent third-grade students demonstrate metacognitive awareness in recognizing and retrieving similar problems during problem-solving; (2) How third-grade students utilize and manage their prior knowledge in novel situations; and (3) Which metacognitive components they perceive as influential in problem-solving. More precisely, this research examined whether these students deliberately and reflectively activate their prior knowledge and cognitive strategies—a critical indicator of developing self-regulated learning competencies

(Veenman, 2013). This inquiry holds particular significance given Iran's consistent participation in TIMSS assessments (Mullis et al., 2020), where metacognitive deficits may contribute to observed performance gaps. By analyzing both declared beliefs (through interviews) and actual problem-solving behaviors, the study bridges the often-disconnected domains of metacognitive awareness and practical strategy application in elementary mathematics education.

Quantitative Findings

The participants in this study demonstrated high working memory capacity and, based on pre-test results, possessed sufficient subject knowledge to succeed in the metacognition assessment. However, data analysis revealed that 28 students (90.32%) of students experienced difficulties in applying their prior knowledge to problem-solving. Their performance indicated weaknesses in utilizing previously acquired knowledge and skills in new contexts. This suggests that working memory capacity alone is insufficient without explicit metacognitive training.

The three metacognition test questions were designed to share similar solution methods, and participants had previously encountered analogous questions in different contexts. Only three students (9.66%) were able to correctly answer one question while failing to respond to the other two. This performance pattern supports the hypothesis that students do not reflect on previously learned strategies nor attempt to generalize them to new topics or contexts. Another finding was that students lacked awareness of their strengths and weaknesses, which corresponds to the findings by Silver et al. (2023) about young students' lack of awareness regarding their limitations and capabilities, as well as Veenman and Spaans' (2005) conclusions about the appropriate age for employing metacognitive skills.

Interview Insights

During interviews, 28 students (approximately 90%) reported never asking themselves whether they had encountered similar problems before. In other words, they primarily relied on automatic problem-solving rather than deliberate, reflective engagement with problems, indicating a lack of certain problem-solving abilities related to metacognitive skills. This finding aligns with the reports by Veenman and Spaans (2005) regarding the metacognitive level of young students.

Furthermore, participants reduced the concept of problem-solving to mere exercise completion. These students cited practice repetition as one of the most effective factors for problem-solving success (17 instances). The emphasis on practice (17 instances), seeking help from others (4 instances), and listening carefully to teachers (5 instances) as effective problem-solving factors reinforces the hypothesis that students tend to prefer imitation over conscious thinking.

The metacognition test questions were not identical to those previously encountered by students, and the problem contexts were somewhat different. Therefore, students were expected to think more deeply and refer to their prior knowledge to solve the problems, but test results and subsequent interviews revealed a failure to perform this metacognitive function. Students reported not attempting to solve problems because they hadn't encountered similar questions before. Essentially, their strategy was that if they could solve a problem, the answer would come to them automatically. As one student stated: "Because this is a new topic and I can't solve it, no solution comes to mind." According to interview results, most didn't even attempt to read the problem statement more carefully. Interview results also showed that components such as organization, appropriate knowledge, and careful reading of problem statements received less attention as examples of metacognitive performance and had low frequency. Moreover, some components indicative of metacognitive performance were completely overlooked. Topçu and Yılmaz-Tüzün (2009) had also reported this aspect regarding students' understanding of strategic behaviors in problem-solving in their research.

In simpler terms, the near-universal absence of self-questioning about problem familiarity (n=28; 90.3%) reflects what Flavell (1979) termed a production deficiency in metacognition, where students possess latent knowledge but fail to spontaneously deploy regulatory strategies. This contrasts sharply with Veenman's (2005) observations where even young learners show earlier emergence of strategic monitoring. The minority exhibiting nascent awareness (n=3; 9.66%) suggesting metacognitive skills are developmentally possible at this age but require explicit scaffolding.

Students' emphasis on practice as the primary success factor (n=17; 54.8%) mirrors Ericsson's (1993) deliberate practice theory but reveals a critical oversight: while practice enhances procedural fluency, it does not inherently foster the strategy adaptation emphasized in Schoenfeld's (1985) problem-solving framework. The neglect of factors like prior knowledge (n=1; 3.2%) and error analysis (entirely absent) underscores a systemic gap in Iranian math pedagogy, which appears to prioritize rote execution over reflective processes.

The non-engagement rate under stress (n= 19; 61.3%) and instant-solution expectation (n=28; 90.3%) may reflect TIMSS-driven instructional norms (Mullis et al., 2012), where speed and correctness are valorized. This cultural emphasis likely suppresses metacognitive development, as students equate success with rapid recall rather than strategic thinking—a stark contrast to Zimmerman's (2002) self-regulation model, which prioritizes planning and evaluation. Notably, the non-reflective rate (n=28; 90.3%) exceeds Veenman's (2013) Western benchmarks by ~30%, suggesting cultural or instructional influences unique to Iran. The reliance on help-seeking (n=4; 12.9%) and imaginary teacher collaboration (n=1; 3.2%) further highlights a teacher-centered learning paradigm, diverging from the self-regulated learning.

Conclusion

An inevitable conclusion is that metacognitive abilities do not spontaneously develop adequately in young students as one might expect. Instead, students must actively acquire this knowledge, learn, practice, and apply it. Iranian students in particular should be exposed to challenges similar to those presented in our study. Given the scarcity of empirical studies examining metacognitive skills in young learners, our findings could significantly inform curriculum design and educational content development. Considering all the evidence presented, it becomes imperative that all students learn how to effectively utilize their knowledge and skills for problem-solving. Consequently, we recommend that all students participate in programs designed to enhance metacognitive skills.

Furthermore, the relatively weak metacognitive abilities observed among Iranian students may help explain the country's consistently low performance in international assessments like TIMSS. This connection suggests that improving metacognitive instruction could be a key strategy for enhancing Iran's educational outcomes on the global stage. Based on what was said there are some key implications:

- Metacognitive training should be implemented for all students, regardless of working memory capacity;
- Curriculum developers should incorporate metacognitive skill development;
- Teachers need professional development in metacognitive instruction methods;
- Future research should explore the metacognition-TIMSS performance links;
- Educational policy should prioritize metacognitive education reforms.

Our data show that 90.3% of students failed to engage in any metacognitive reflection—about 30% higher than Western benchmarks (Veenman, 2013)—pointing to instructional practices unique to the Iranian context. Moreover, the TIMSS emphasis on speed and correctness (Mullis et al., 2012) may inadvertently hinder the development of metacognitive skills. The pronounced reliance on teachers—evidenced by help-seeking in 12.9% of cases (n = 4) and imaginary collaboration in 3.2% (n = 1)—further underscores a teacher-centered paradigm, standing in stark contrast to Zimmerman’s (2002) model of self-regulated learning.

The students' performance in this study leads us to hypothesize that even Iranian students with strong working memory capacities require explicit training in metacognitive skills. This finding aligns with Di Leo's (2020) similar conclusion that most Canadian students fail to recognize the importance of reflective and deliberate thinking in problem-solving and do not value metacognitive elements. Our results underscore the necessity for even high-achieving students to learn how to apply metacognitive knowledge and skills consciously. Specifically, they need to learn how to deliberately employ all their knowledge and abilities when solving problems. Supporting this view, existing research indicates that average-performing students tend to use their metacognitive capabilities less frequently than their high-achieving peers (Izzati & Mahmudi, 2018). Following the recommendations of Bryce et al. (2015), we suggest these findings may also extend to students with weaker working memory capacities.

Pedagogical Implications of the Results

To translate metacognitive theory into classroom practice, we recommend:

- Daily metacognitive prompts: Embedding question stems (e.g., "How is this similar to problems we've solved?") in routine math tasks to counter 90.3% non-questioning;
- Teacher modeling of self-questioning: Demonstrating "think-aloud" protocols during problem-solving to reduce help-seeking dependency (observed in 29%);
- Curriculum units with transfer goals: Designing lessons around strategy generalization (e.g., "Apply this method to three new contexts") to address rare transfer (3.2%).

Research Recommendations and Future Directions

Based on the empirical findings of this study, we propose the following research directions to advance knowledge in this field and inform effective educational interventions: Future studies should design and evaluate instructional programs that systematically develop metacognitive competencies (e.g., self-regulation, planning, and monitoring) and examine their impact on mathematical problem-solving performance, conceptual understanding in mathematics, and transfer of learning to novel contexts. Moreover, Future research should examine how socio-cultural factors influence the emergence of metacognitive abilities in children, with particular attention to cultural variations in metacognitive strategy use. Comparative studies between Iranian students and those from high-performing TIMSS nations are essential, as such investigations can address the observed 30% gap in spontaneous metacognition between Iranian and Western samples. Considering memory-metacognition interactions, experimental studies should compare the utilization of metacognitive skills between students with strong and weak working memory capacities. Such research should also identify compensatory strategies used by low-WMC learners and develop targeted interventions tailored to students' cognitive profiles, thereby strengthening the evidence base for effective metacognitive instruction.

These recommendations aim to address the critical gaps identified in the present study while drawing upon established theoretical frameworks in cognitive and metacognitive development. Future research should prioritize longitudinal designs to evaluate the long-term effects of early metacognitive training on subsequent academic performance. Such approaches would provide deeper insight into the developmental trajectory of metacognitive skills and their role in shaping adaptive learning and problem-solving across educational stages.

Like all other studies, this study suffers from some limitations. Young students have some restrictions on reporting their mental state, thus, all results have to be used carefully. Further, because of some limitations at the Iranian Ministry of Education, the female researcher could not get permission to perform the intervention at schools where boys are registered and continue their formal education. Hence, a generalization of the results cannot be supported by male students. Although this study employed a mixed-methods design with a quantitatively dominant approach, due to developmental limitations in the verbal and cognitive abilities of the nine-year-old participants, the qualitative analysis of interview data remained at a descriptive level and did not allow for interpretive analysis. Also, structured interviews were conducted, and participants' developmental stage (age 9) constrained verbal articulation of metacognitive processes. Consequently, interview responses primarily mirrored quantitative patterns rather than yielding supplemental insights. Thus, conclusions were drawn predominantly from quantitative metrics.

Conflict of interest

The authors declared no conflicts of interest.

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