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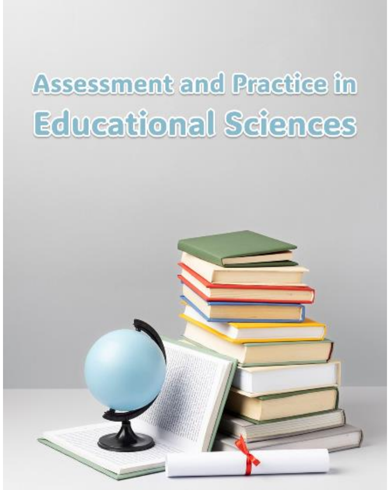

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The Effectiveness of Metacognitive Mathematics Training on Problem-Solving Performance, Self-Regulated Learning, and Mathematical Self-Efficacy

ABSTRACT

The present study aimed to determine the effectiveness of metacognitive mathematics training on problem-solving performance, self-regulated learning, and mathematical self-efficacy among secondary-school students in Tehran. This study employed a quasi-experimental pretest-posttest control-group design with a two-month follow-up. The statistical population consisted of secondary-school students in Tehran during the 2025–2026 academic year. A total of 30 eligible students were selected through purposive sampling and randomly assigned to an experimental group ($n = 15$) and a control group ($n = 15$). The experimental group participated in eight 90-minute sessions of metacognitive mathematics training conducted twice weekly, while the control group continued receiving regular mathematics instruction. Data were collected using a researcher-developed Mathematical Problem-Solving Performance Test, a self-regulated learning measure, and a Mathematics Self-Efficacy Scale. Data were analyzed using mixed-design repeated-measures analysis of variance and Bonferroni-adjusted post-hoc comparisons in SPSS. Mixed repeated-measures analysis showed significant time-by-group interaction effects for problem-solving performance, $F(2, 56) = 54.91$, $p < .001$, partial $\eta^2 = .662$; self-regulated learning, $F(2, 56) = 78.46$, $p < .001$, partial $\eta^2 = .737$; and mathematical self-efficacy, $F(2, 56) = 65.72$, $p < .001$, partial $\eta^2 = .701$. Bonferroni comparisons indicated significant improvements from pretest to posttest and from pretest to follow-up in all three outcomes (all $p < .001$), whereas the differences between posttest and follow-up were not statistically significant for problem-solving performance ($p = .451$), self-regulated learning ($p = .281$), or mathematical self-efficacy ($p = .274$). Metacognitive mathematics training was effective in improving students' mathematical problem-solving performance, self-regulated learning, and mathematical self-efficacy, and these gains were maintained at the two-month follow-up. The findings support the integration of explicit planning, monitoring, self-questioning, error correction, and evaluation strategies into mathematics instruction to strengthen both academic performance and students' regulatory and motivational competencies.

Keywords: Metacognitive Training, Mathematics Education, Problem-Solving Performance, Self-Regulated Learning, Mathematical Self-Efficacy, Secondary-School Students

Introduction

Mathematics is a fundamental domain of formal education because it develops logical reasoning, analytical thinking, quantitative literacy, and the capacity to approach complex problems systematically. Success in mathematics, however, depends on more than mastery of formulas and computational procedures. Students are frequently required to interpret unfamiliar situations, identify relevant information, formulate appropriate strategies, monitor their progress, detect errors, and evaluate the plausibility of their solutions. These processes transform mathematical learning from a predominantly procedural activity into a complex cognitive and metacognitive endeavor. Accordingly, contemporary perspectives on mathematics education increasingly emphasize the development of learners who are able not only to perform mathematical operations but also to regulate and evaluate their own thinking. Within this framework, mathematical problem-solving performance, self-regulated learning, and mathematical self-efficacy are particularly important because they jointly influence how students approach difficult mathematical tasks, persist when confronted with obstacles, and adapt their strategies when an initial solution is unsuccessful (1, 2).

Mathematical problem solving is widely considered one of the most important indicators of meaningful mathematics learning. It requires students to move beyond the reproduction of memorized algorithms and instead engage in comprehension, representation, planning, strategy selection, execution, monitoring, and evaluation. A student may possess sufficient mathematical knowledge but still experience difficulty solving problems if that knowledge is not strategically organized and effectively deployed. Problem-solving performance therefore reflects an interaction between domain-specific knowledge and higher-order regulatory processes. Research has demonstrated that students who exhibit stronger metacognitive skills tend to be more capable of identifying the demands of mathematical problems, selecting appropriate approaches, checking their work, and modifying ineffective strategies (2). Similarly, evidence concerning students' metacognitive consciousness in geometric problem solving indicates that awareness of one's own cognitive processes is closely related to the ability to organize and regulate mathematical reasoning during complex tasks (3). These findings suggest that difficulties in mathematics cannot always be attributed solely to insufficient conceptual knowledge; deficiencies in metacognitive regulation may also play a central role.

The concept of metacognition provides a useful theoretical framework for understanding these processes. Metacognition generally refers to an individual's knowledge and regulation of his or her own cognitive activity. It encompasses awareness of personal strengths and limitations, knowledge about tasks and strategies, planning before beginning a task, monitoring cognitive processes during performance, and evaluating outcomes after task completion. In mathematical problem solving, metacognition allows students to ask themselves whether they understand the problem, whether the strategy they have chosen is appropriate, whether their calculations are moving them toward the intended goal, and whether their final answer is reasonable. Metacognitive processes therefore operate as a regulatory system that organizes cognitive resources and helps learners respond adaptively to changing task demands. Flavell's conceptualization of metacognition has had a foundational role in explaining how learners become conscious of their thought processes and deliberately regulate them during problem solving (1). This perspective is particularly relevant to mathematics, where successful performance often depends on continuous transitions between understanding, strategic planning, implementation, error detection, and evaluation.

Metacognitive processes appear especially important when students encounter mathematical tasks characterized by novelty, complexity, or uncertainty. Under such conditions, automatic application of previously learned procedures may be insufficient, and students must allocate attention, select among competing strategies, and continuously determine whether their approach remains effective. The Regulated Attention in Mathematical Problem Solving framework highlights the interaction between metacognitive cues, working memory, attention regulation, and mathematics anxiety, showing that successful mathematical problem solving requires learners to direct limited cognitive resources strategically (4). When students can recognize signs of confusion or cognitive overload, they may be better able to slow down, reconsider the task, select an alternative strategy, or verify previous steps. Conversely, limited metacognitive awareness may lead students to continue ineffective strategies, overlook errors, or abandon a solvable problem prematurely.

Empirical research in mathematics education supports the relationship between metacognitive awareness and mathematical performance. Lao and Divinagracia demonstrated the importance of metacognitive awareness when evaluating the performance of Grade 8 mathematics learners, suggesting that students' capacity to reflect on their own thinking provides meaningful information beyond conventional measures of achievement (5). Suliani and colleagues likewise showed that students' mathematical beliefs influence their metacognitive skills during mathematical problem solving, indicating that cognition and beliefs operate interactively rather than independently during solution processes (6). Students who view mathematics as understandable, manageable, and responsive to strategic effort may be more inclined to monitor and regulate their cognitive activity, whereas those who perceive mathematics as fixed, inaccessible, or dependent primarily on innate ability may be less likely to engage in sustained metacognitive reflection.

Metacognition is also closely connected with self-regulated learning. Self-regulated learning refers to the process through which students actively manage their cognition, motivation, behavior, and learning environment in pursuit of academic goals. Self-regulated learners establish goals, select suitable strategies, monitor their progress, manage effort, respond to feedback, and modify their behavior when necessary. From this perspective, metacognition constitutes one of the central mechanisms of self-regulation because students cannot effectively control their learning unless they are able to monitor their understanding and evaluate the effectiveness of their strategies. In mathematics, self-regulation becomes particularly important because difficult problems often require sustained effort, strategic flexibility, and tolerance of temporary failure. Students who possess self-regulatory skills are more likely to persist, evaluate errors constructively, and use alternative methods rather than interpreting difficulty as evidence of inability.

The relationship between metacognition and broader problem-solving competence is also supported by findings outside narrowly defined mathematics tasks. Yunus and colleagues found meaningful relationships among achievement motivation, metacognitive awareness, attitudes, and problem-solving ability, emphasizing that problem solving develops within an integrated motivational and cognitive system (7). Mam-Sharifi and colleagues similarly showed that problem-solving strategies can play a mediating role in relationships involving metacognitive beliefs and adaptive psychological functioning, illustrating the regulatory significance of problem-solving processes in managing challenging situations (8). Although such findings extend beyond mathematics education specifically, they reinforce the theoretical argument that metacognition facilitates adaptive problem solving by enabling individuals to evaluate their cognitive responses and select more effective strategies.

Another key variable in mathematics learning is self-efficacy. Self-efficacy refers to individuals' beliefs regarding their capacity to organize and perform the actions required to accomplish particular tasks. Mathematical self-efficacy is therefore concerned with students' confidence in their ability to understand mathematics, complete assignments, solve problems, learn unfamiliar mathematical concepts, and succeed in assessments. These beliefs can influence whether students initiate a difficult task, the amount of effort they invest, how long they persist when confronted with obstacles, and how they interpret errors. Students with stronger mathematical self-efficacy are generally more willing to attempt challenging problems and to perceive difficulty as manageable, whereas students with weaker self-efficacy may avoid demanding tasks, disengage rapidly, or interpret temporary failure as confirmation of low ability.

The association between self-efficacy and metacognition has received increasing empirical attention. Tak and colleagues found that metacognitive awareness mediated the relationship between self-efficacy and mathematical reasoning, suggesting that confidence in one's capabilities may contribute to performance partly by promoting more effective monitoring and regulation of cognition (9). Similarly, Fitri and colleagues reported that metacognition played a mediating role in the relationship between self-efficacy and problem-solving performance, further supporting the proposition that students' beliefs about their capabilities are linked to how effectively they manage their thinking during complex tasks (10). From this perspective, self-efficacy and metacognition should not be considered independent educational outcomes. Instead, they may operate reciprocally: stronger self-efficacy can encourage sustained strategic engagement, while successful metacognitive regulation may generate mastery experiences that further strengthen efficacy beliefs.

Studies conducted in educational contexts have also identified meaningful relationships between metacognitive beliefs and academic self-efficacy. Karimi and colleagues showed that metacognitive beliefs were related to academic self-efficacy among students in Tehran, with working memory contributing to the relationship between these constructs (11). Kamyabi and colleagues likewise identified metacognitive beliefs as an important mediating mechanism in a model involving self-efficacy, perfectionism, and academic procrastination (12). Related findings reported by Kamyabi Mitra and colleagues further emphasized the role of metacognitive beliefs in connecting students' self-perceptions with maladaptive academic behaviors such as procrastination (13). Collectively, these studies indicate that students' beliefs about cognition and their perceived academic capability are intertwined with patterns of engagement and persistence, making metacognition a promising target for educational intervention.

The relevance of metacognition for students experiencing learning difficulties is particularly important. Students with persistent problems in reading, writing, or mathematics may repeatedly encounter academic failure, which can contribute to ineffective strategy use, avoidance behaviors, and reduced confidence. Afshari and colleagues demonstrated that metacognitive training can reduce mathematics-related difficulties among students with learning disorders, suggesting that explicit instruction in monitoring and regulating cognitive processes may help compensate for weaknesses in conventional learning approaches (14). Likewise, Nourozzade and Soleimani reported structural relationships among metacognitive awareness, self-efficacy, academic motivation, attitudes toward mathematics, and mathematical anxiety in students with special learning disabilities (15). These findings highlight the multidimensional character of mathematics learning and indicate that intervention should address not only academic skills but also the cognitive, emotional, and motivational processes surrounding mathematical performance.

Metacognitive interventions may be particularly effective because they teach learners procedures that can be generalized across different mathematical tasks. Rather than presenting only content-specific solutions, metacognitive mathematics training can teach students to pause before beginning a problem, clarify the objective, distinguish relevant from irrelevant information, activate prior knowledge, generate alternative strategies, monitor the effectiveness of the selected strategy, identify errors, and evaluate the final solution. Such training can also employ self-questioning, think-aloud demonstrations, reflective prompts, and guided practice to make normally implicit cognitive processes explicit. Over time, students may internalize these strategies and apply them independently. Tsampouris and Requena demonstrated the relevance of metacognitive strategies to logical-mathematical thinking among adolescents with attention-deficit/hyperactivity disorder, emphasizing that structured metacognitive guidance can support reasoning even in populations characterized by attentional and executive challenges (16).

Evidence from intervention studies further suggests that direct instruction in cognitive and metacognitive strategies can improve motivational as well as academic outcomes. Rashidi and colleagues found that training in self-regulated learning strategies, including cognitive and metacognitive components, improved students' self-efficacy and academic motivation while also contributing to psychological outcomes (17). Taghani and Razavi similarly reported that metacognitive study-strategy training improved academic self-efficacy, academic engagement, and performance among female students (18). Shoaei and colleagues found that metacognitive strategy training was effective in relation to academic self-efficacy and test anxiety among secondary-school female students, demonstrating the potential of metacognitive interventions to influence both students' beliefs about competence and their emotional responses to academic evaluation (19). These results are particularly relevant to mathematics education because mathematics performance is often shaped by the interaction of cognitive demand, perceived competence, and anxiety.

Different learning environments may also facilitate metacognitive development when they encourage active monitoring and reflection. Honelly reported that a flipped classroom environment was associated with academic achievement, self-efficacy, and metacognitive awareness, showing that instructional structures that promote learner responsibility and active engagement may enhance both cognitive and motivational processes (20). Although flipped learning differs from explicit metacognitive mathematics training, both approaches shift students away from passive reception and toward active involvement in the learning process. This supports the broader argument that educational interventions are more likely to produce durable learning when students are taught how to think about and regulate their own learning rather than merely receiving additional academic content.

The motivational dimension of mathematical learning further strengthens the rationale for integrating metacognitive strategies into instruction. Moustakas and Gonida identified distinct motivational profiles among high achievers in mathematics and demonstrated relationships between these profiles, metacognitive processes, and achievement emotions (21). This suggests that even among academically successful students, variations in metacognitive regulation and emotional experience may influence how achievement is maintained. Mathematics learning should therefore be understood as a coordinated system in which cognition, metacognition, motivation, emotion, and beliefs about competence jointly shape performance. Metacognitive training may be especially valuable because it directly targets regulatory processes while indirectly affecting other elements of this system.

Despite the growing body of research, several issues warrant further investigation. Many studies have examined metacognition in relation to a single outcome, such as academic achievement, mathematics anxiety, self-efficacy, or general problem-solving ability. Fewer studies have simultaneously considered mathematical problem-solving performance, self-regulated learning, and mathematical self-efficacy as interconnected outcomes of a structured metacognitive mathematics intervention. Yet these variables represent complementary dimensions of mathematics learning: problem-solving performance reflects observable academic functioning, self-regulated learning reflects students' capacity to control and organize learning processes, and mathematical self-efficacy reflects confidence in performing mathematics-related tasks. Examining these outcomes together can provide a more comprehensive understanding of whether metacognitive instruction affects not only what students achieve but also how they regulate learning and how capable they perceive themselves to be.

Furthermore, mathematics education within highly achievement-oriented educational environments may place considerable emphasis on correct answers and examination performance, sometimes at the expense of explicit instruction in planning, monitoring, error analysis, and reflective evaluation. Under these circumstances, students may acquire substantial procedural knowledge without developing adequate awareness of how to regulate their mathematical thinking. Structured metacognitive mathematics training can address this gap by making strategic thinking an explicit instructional objective. By teaching students to understand the demands of a problem before attempting a solution, monitor the adequacy of their approach, regulate effort and attention, and evaluate both the process and outcome, such training may enhance performance while simultaneously strengthening self-regulatory competence and efficacy beliefs. The converging evidence linking metacognition with mathematical reasoning, self-efficacy, strategic learning, academic engagement, and problem solving provides a strong theoretical and empirical foundation for examining this instructional approach (2, 6, 9, 17).

Accordingly, the aim of the present study was to determine the effectiveness of metacognitive mathematics training on problem-solving performance, self-regulated learning, and mathematical self-efficacy among secondary-school students in Tehran.

Methods and Materials

Study Design and Particiapnts

This study employed a quasi-experimental research design with a pretest-posttest control group and a follow-up assessment to investigate the effectiveness of metacognitive mathematics training on mathematical problem-solving performance, self-regulated learning, and mathematical self-efficacy among students in Tehran, Iran. The statistical population consisted of secondary-school students enrolled in public schools in Tehran during the 2025–2026 academic year. A total of 30 students who met the eligibility criteria were selected through purposive sampling and subsequently assigned randomly to an experimental group receiving metacognitive mathematics training (n = 15) and a control group (n = 15). The inclusion criteria were being enrolled as a secondary-school student in Tehran, demonstrating an average or below-average level of mathematics performance based on the most recent school assessment, having no previous participation in a structured metacognitive mathematics training program, being willing to participate in the study, obtaining written parental consent, and being able to attend the intervention sessions regularly. Students were excluded if they were absent from more than two intervention sessions, participated simultaneously in another structured educational or psychological intervention related to mathematics learning, voluntarily withdrew from the study, or failed to complete the study assessments. After obtaining the required administrative permissions, eligible students and their parents were informed about the objectives and procedures of the research. Participants were assured that participation was voluntary, their information would remain confidential, and they could withdraw from the study at any stage without any academic consequences. Before the intervention, both groups completed the measures of mathematical problem-solving performance, self-regulated learning, and mathematical self-efficacy as the pretest. The experimental group then participated in the metacognitive mathematics training program, whereas the control group continued to receive the regular mathematics curriculum without additional metacognitive instruction. Immediately after completion of the intervention, both groups completed the same measures as the posttest. To determine the stability of the intervention effects, a follow-up assessment was conducted two months after the posttest. The intervention and assessments were implemented under similar conditions for participants, and efforts were made to minimize communication regarding the specific instructional content between students assigned to the two groups.

Data Collection Tools

Mathematical problem-solving performance was assessed using a researcher-developed Mathematical Problem-Solving Performance Test designed in accordance with the mathematics curriculum appropriate to the participants' educational level. The test consisted of 12 open-ended mathematical problems requiring students to analyze the problem, identify relevant information, select an appropriate solution strategy, perform the necessary mathematical operations, and evaluate the accuracy and reasonableness of the obtained solution. The items were developed to measure higher-order mathematical problem-solving rather than simple computational ability and included problems requiring multistep reasoning and the application of previously learned mathematical concepts to relatively unfamiliar situations. Responses were scored using an analytical scoring rubric that considered problem comprehension, identification and selection of an appropriate strategy, implementation of the strategy, computational accuracy, and evaluation of the final solution. Higher scores represented better mathematical problem-solving performance. To establish content validity, the initial version of the instrument was reviewed by specialists in mathematics education, educational psychology, and curriculum studies, and revisions were made based on their comments concerning item clarity, relevance, difficulty, and correspondence with the study objectives. The internal consistency and scoring reliability of the test were examined in a preliminary administration before its use in the main study, indicating satisfactory reliability for assessing mathematical problem-solving performance.

Self-regulated learning was evaluated using the Motivated Strategies for Learning Questionnaire developed by Pintrich and colleagues. The questionnaire assesses students' cognitive, metacognitive, motivational, and resource-management processes involved in the regulation of learning. Items address learning behaviors such as goal setting, planning, organization, elaboration, monitoring of comprehension, management of effort, persistence when encountering difficult academic tasks, regulation of study activities, and evaluation of learning progress. Participants indicated the extent to which each statement described their usual learning behavior using a Likert-type response format ranging from low to high correspondence with their learning practices. Higher total scores indicated a greater tendency to use self-regulatory strategies during academic learning. The questionnaire has been extensively employed in educational research and has demonstrated satisfactory evidence of construct validity and internal consistency. For the present study, the Persian version appropriate for the target population was used, and the internal consistency of the scale was reassessed using Cronbach's alpha coefficient to ensure satisfactory reliability within the study sample.

Mathematical self-efficacy was measured using a Mathematics Self-Efficacy Scale assessing students' perceived confidence in their ability to understand mathematical concepts, successfully complete mathematics assignments, solve mathematical problems of varying levels of difficulty, learn unfamiliar mathematical material, select effective strategies when facing challenging problems, and achieve satisfactory performance in mathematics examinations. The instrument required participants to rate their degree of confidence regarding a series of mathematics-related tasks and learning situations on a Likert-type scale. Higher scores reflected stronger mathematical self-efficacy and greater confidence in successfully performing mathematics-related activities. The scale was selected because mathematical self-efficacy represents a task-specific belief concerning students' perceived capability to organize and execute the actions necessary for successful mathematical performance. The Persian version was reviewed for linguistic clarity and correspondence with the educational context of Iranian students. Content appropriateness was evaluated by experts in educational psychology and mathematics education, and the reliability of the scale in the present sample was examined using Cronbach's alpha coefficient. The questionnaires were administered under standardized classroom conditions at all three assessment stages, and participants received identical instructions regarding completion of the instruments.

Intervention Protocol

The metacognitive mathematics training program was administered to the experimental group in eight 90-minute sessions conducted twice weekly. The intervention was designed to integrate explicit metacognitive instruction into mathematical problem-solving activities and focused on developing students' awareness, planning, monitoring, regulation, and evaluation of their cognitive processes while solving mathematical problems. In the initial sessions, students were introduced to the concept of metacognition and learned to distinguish between simply performing mathematical operations and consciously thinking about how a mathematical problem should be approached. They were trained to identify what they already knew, determine what information was provided and what was required, recognize potentially relevant mathematical concepts, and establish a clear goal before beginning a solution. Subsequent sessions emphasized planning skills, including decomposition of complex problems into manageable components, comparison of alternative solution strategies, prediction of possible difficulties, estimation of the time and resources required for solving a problem, and selection of an appropriate strategy before performing mathematical operations. The monitoring component trained students to use self-questioning throughout the problem-solving process, such as asking whether they understood the problem correctly, whether the selected strategy was appropriate, whether each computational step was consistent with the original goal, and whether modifications were necessary when the selected strategy was unsuccessful. Students were explicitly encouraged to verbalize their thinking processes and explain the rationale underlying their mathematical decisions. The regulation component focused on recognizing errors, changing ineffective strategies, managing frustration when encountering difficult problems, maintaining attention, and using feedback to revise the solution process. Later sessions emphasized evaluation and reflective thinking by teaching students to examine whether their final answers were logically and mathematically reasonable, identify the reasons for successful or unsuccessful performance, compare different methods of solving the same problem, and determine how strategies learned during one problem could be transferred to new mathematical tasks. Instructor modeling, guided practice, think-aloud demonstrations, collaborative problem solving, metacognitive questioning, individual practice, feedback, and reflective exercises were used throughout the intervention. Homework assignments were also provided to encourage students to apply the planning-monitoring-evaluation cycle independently outside the training sessions. During the final session, the principal metacognitive strategies were reviewed and integrated, and students practiced applying the complete sequence of understanding the problem, planning, strategy selection, implementation, monitoring, error correction, and evaluation independently. The control group did not receive the metacognitive training during the study period and continued its usual mathematics instruction.

Data Analysis

Data analysis was conducted using IBM SPSS Statistics. Descriptive statistics, including mean, standard deviation, minimum and maximum scores, were calculated for mathematical problem-solving performance, self-regulated learning, and mathematical self-efficacy separately for the experimental and control groups across the pretest, posttest, and follow-up assessments. Before conducting inferential analyses, the data were screened for missing values, data-entry errors, and extreme observations. The assumptions required for parametric analysis were also examined. Normality of the dependent-variable distributions was evaluated using the Shapiro–Wilk test together with skewness and kurtosis indices. Homogeneity of error variances was examined using Levene's test, and the homogeneity of covariance matrices was assessed where appropriate. Because each participant was assessed repeatedly at three measurement occasions, Mauchly's test of sphericity was used to examine the sphericity assumption, and the Greenhouse–Geisser correction was applied when this assumption was violated. A mixed-design repeated-measures analysis of variance was subsequently conducted to determine changes in mathematical problem-solving performance, self-regulated learning, and mathematical self-efficacy across time and to examine whether these changes differed significantly between the experimental and control groups. The within-subject factor consisted of assessment time at three levels, namely pretest, posttest, and follow-up, whereas the between-subject factor consisted of the experimental and control groups. Particular attention was given to the group-by-time interaction effect because a statistically significant interaction would indicate that changes in the dependent variables over time differed according to participation in the metacognitive mathematics training program. Effect sizes were reported using partial eta squared to determine the magnitude of the observed intervention effects. When significant time or interaction effects were identified, Bonferroni-adjusted pairwise comparisons were performed to determine differences between the pretest, posttest, and follow-up assessments and to evaluate the maintenance of intervention effects during the follow-up period. All statistical tests were two-tailed, and the significance level was set at $p < .05$.

Findings and Results

The participants included 30 secondary-school students from Tehran who were randomly assigned to the experimental group receiving metacognitive mathematics training ($n = 15$) and the control group ($n = 15$). The mean age of the participants was

15.47 years (SD = 0.51), with no statistically significant difference between the experimental group (M = 15.53, SD = 0.52) and the control group (M = 15.40, SD = 0.51) in terms of age ($p > .05$). Regarding gender distribution, 16 participants (53.3%) were female and 14 participants (46.7%) were male. In the experimental group, 8 participants (53.3%) were female and 7 (46.7%) were male, whereas the control group included 8 female students (53.3%) and 7 male students (46.7%). The two groups were therefore comparable in terms of gender distribution. Moreover, all participants were enrolled in secondary schools in Tehran and were studying at approximately the same educational level. No statistically significant between-group differences were observed in the principal demographic characteristics at baseline, indicating that the experimental and control groups were relatively homogeneous prior to implementation of the intervention.

Table 1. Descriptive Statistics for Problem-Solving Performance, Self-Regulated Learning, and Mathematical Self-Efficacy Across the Three Measurement Stages

Variable	Group	Pretest M	Pretest SD	Posttest M	Posttest SD	Follow-up M	Follow-up SD
Problem-Solving Performance	Experimental	24.13	4.21	34.67	4.36	33.87	4.18
	Control	24.40	4.07	25.33	4.12	25.07	4.25
Self-Regulated Learning	Experimental	82.47	9.18	104.73	9.64	102.87	9.37
	Control	83.13	9.42	85.07	9.51	84.60	9.65
Mathematical Self-Efficacy	Experimental	48.27	6.84	63.80	6.92	62.47	6.78
	Control	48.73	6.71	50.20	6.83	49.87	6.89

As shown in Table 1, the experimental and control groups had relatively similar mean scores for all three dependent variables at the pretest stage. For problem-solving performance, the experimental group increased from a mean of 24.13 (SD = 4.21) at pretest to 34.67 (SD = 4.36) at posttest, with the improvement largely maintained at follow-up (M = 33.87, SD = 4.18). In contrast, only a small change was observed in the control group, with mean scores increasing from 24.40 (SD = 4.07) at pretest to 25.33 (SD = 4.12) at posttest and 25.07 (SD = 4.25) at follow-up. A similar pattern was observed for self-regulated learning. The experimental group demonstrated a substantial increase from 82.47 (SD = 9.18) at pretest to 104.73 (SD = 9.64) at posttest, and the score remained high at follow-up (M = 102.87, SD = 9.37). However, the corresponding changes in the control group were relatively small. Mathematical self-efficacy also increased considerably in the experimental group, from 48.27 (SD = 6.84) at pretest to 63.80 (SD = 6.92) at posttest, and remained relatively stable at follow-up (M = 62.47, SD = 6.78). In comparison, the control group demonstrated only minor changes across the three measurement occasions. These descriptive findings suggest that metacognitive mathematics training was associated with improvements in all three dependent variables and that these improvements were largely sustained during the follow-up period.

Before conducting the repeated-measures analysis of variance, the relevant statistical assumptions were examined. The Shapiro–Wilk test indicated that the distributions of problem-solving performance, self-regulated learning, and mathematical self-efficacy scores did not significantly deviate from normality across the experimental and control groups and at the three measurement stages, with all p values greater than .05. Skewness and kurtosis coefficients were also within the acceptable range of ±2. Levene's test indicated that the assumption of homogeneity of variances was satisfied for problem-solving performance at pretest, posttest, and follow-up ($p = .741$, $p = .628$, and $p = .594$, respectively), self-regulated learning ($p = .683$, $p = .527$, and $p = .611$, respectively), and mathematical self-efficacy ($p = .792$, $p = .655$, and $p = .703$, respectively). Box's M test was not statistically significant (Box's M = 18.42, $F = 1.17$, $p = .281$), supporting the homogeneity of covariance matrices. Mauchly's test of sphericity was also nonsignificant for problem-solving performance ($W = .91$, $p = .296$), self-regulated learning ($W = .89$, $p = .218$), and mathematical self-efficacy ($W = .92$, $p = .337$), indicating that the assumption of sphericity was satisfied. Therefore, the assumptions necessary for conducting the mixed repeated-measures analysis of variance were adequately met.

Table 2. Mixed Repeated-Measures Analysis of Variance for the Study Variables

Variable	Source	df	F	p	Partial η²
Problem-Solving Performance	Time	2, 56	72.84	< .001	.722
	Group	1, 28	20.63	< .001	.424
	Time × Group	2, 56	54.91	< .001	.662
Self-Regulated Learning	Time	2, 56	96.37	< .001	.775
	Group	1, 28	21.84	< .001	.438
	Time × Group	2, 56	78.46	< .001	.737
Mathematical Self-Efficacy	Time	2, 56	83.19	< .001	.748
	Group	1, 28	18.97	< .001	.404
	Time × Group	2, 56	65.72	< .001	.701

The results of the mixed repeated-measures analysis of variance presented in Table 2 indicated a statistically significant main effect of time on problem-solving performance, $F(2, 56) = 72.84$, $p < .001$, partial $\eta^2 = .722$, demonstrating significant changes in problem-solving scores across the three measurement stages. The main effect of group was also significant, $F(1, 28) = 20.63$, $p < .001$, partial $\eta^2 = .424$. More importantly, the interaction between time and group was statistically significant, $F(2, 56) = 54.91$, $p < .001$, partial $\eta^2 = .662$, indicating that changes in problem-solving performance over time differed significantly between the experimental and control groups. For self-regulated learning, significant effects were also observed for time, $F(2, 56) = 96.37$, $p < .001$, partial $\eta^2 = .775$, and group, $F(1, 28) = 21.84$, $p < .001$, partial $\eta^2 = .438$. The significant time-by-group interaction, $F(2, 56) = 78.46$, $p < .001$, partial $\eta^2 = .737$, indicated that the improvement in self-regulated learning was substantially greater in the experimental group. Similarly, mathematical self-efficacy showed significant main effects of time, $F(2, 56) = 83.19$, $p < .001$, partial $\eta^2 = .748$, and group, $F(1, 28) = 18.97$, $p < .001$, partial $\eta^2 = .404$, together with a significant time-by-group interaction, $F(2, 56) = 65.72$, $p < .001$, partial $\eta^2 = .701$. The relatively large effect sizes obtained for the interaction effects indicate that metacognitive mathematics training had a substantial effect on problem-solving performance, self-regulated learning, and mathematical self-efficacy over time.

Table 3. Bonferroni Pairwise Comparisons Across Measurement Stages in the Experimental Group

Variable	Comparison	Mean Difference	SE	p
Problem-Solving Performance	Pretest – Posttest	-10.54	1.18	< .001
	Pretest – Follow-up	-9.74	1.21	< .001
	Posttest – Follow-up	0.80	0.54	.451
Self-Regulated Learning	Pretest – Posttest	-22.26	2.31	< .001
	Pretest – Follow-up	-20.40	2.38	< .001
	Posttest – Follow-up	1.86	1.07	.281
Mathematical Self-Efficacy	Pretest – Posttest	-15.53	1.62	< .001
	Pretest – Follow-up	-14.20	1.67	< .001
	Posttest – Follow-up	1.33	0.76	.274

The Bonferroni-adjusted pairwise comparisons presented in Table 3 further clarified the pattern of changes observed in the experimental group. For problem-solving performance, the mean score at posttest was significantly higher than at pretest, with a mean difference of 10.54 points ($p < .001$), and the follow-up score was also significantly higher than the pretest score, with a mean difference of 9.74 points ($p < .001$). However, the difference between posttest and follow-up was not statistically significant ($p = .451$), indicating that the improvement in problem-solving performance was maintained during the follow-up period. A comparable pattern was observed for self-regulated learning. Scores increased significantly from pretest to posttest by 22.26 points ($p < .001$) and from pretest to follow-up by 20.40 points ($p < .001$), whereas the difference between posttest and follow-up was nonsignificant ($p = .281$). These findings suggest sustained improvement in students' self-regulated learning following the intervention. For mathematical self-efficacy, a significant increase of 15.53 points was observed between pretest and posttest ($p < .001$), and the follow-up score remained significantly higher than the pretest score, with a mean difference of 14.20 points ($p < .001$). The difference between posttest and follow-up was not statistically significant ($p = .274$). Overall, the post-hoc findings demonstrate that metacognitive mathematics training produced significant improvements in problem-solving performance, self-regulated learning, and mathematical self-efficacy from pretest to posttest, and that these improvements were maintained two months after completion of the intervention.

Discussion and Conclusion

The present study investigated the effectiveness of metacognitive mathematics training on problem-solving performance, self-regulated learning, and mathematical self-efficacy among secondary-school students in Tehran. The findings showed that students who received metacognitive mathematics training demonstrated significantly greater improvements in all three dependent variables compared with the control group. Specifically, the experimental group showed substantial increases in mathematical problem-solving performance, self-regulated learning, and mathematical self-efficacy from pretest to posttest, whereas the control group exhibited only minor changes. The significant time-by-group interaction effects further indicated that the pattern of change across the three assessment stages differed between the two groups. Moreover, the post-hoc comparisons showed that the gains observed in the experimental group remained statistically significant at the two-month follow-up, while there were no significant differences between posttest and follow-up scores. These findings suggest that metacognitive mathematics training not only produced immediate improvements in students' mathematical and self-regulatory functioning but also contributed to the maintenance of these effects over time.

The first major finding concerned the significant improvement in mathematical problem-solving performance among students who participated in metacognitive mathematics training. This result is consistent with previous research showing that metacognitive processes are closely associated with successful mathematical problem solving. Güner and Erbay emphasized that metacognitive skills play an essential role in problem-solving performance because students who are better able to plan, monitor, and evaluate their cognitive activity are more capable of selecting suitable strategies and correcting mistakes during solution processes (2). Similarly, Yakubu and colleagues showed that metacognitive consciousness is strongly relevant to students' ability to solve geometric problems, particularly when mathematical tasks require deliberate reasoning and monitoring rather than routine application of memorized procedures (3). Lao and Divinagracia also reported that metacognitive awareness was closely linked with mathematics performance, supporting the importance of reflective awareness in understanding how learners approach mathematical tasks (5). Therefore, the improvement observed in the present study is consistent with the broader evidence that mathematical problem solving can be strengthened when students are explicitly trained to regulate their thinking.

This finding can be explained by considering the structure of the intervention. Metacognitive mathematics training required students to move through a systematic process of understanding the problem, identifying known and unknown information, planning a strategy, monitoring progress, evaluating intermediate steps, detecting errors, and judging the reasonableness of the final answer. Such instruction likely reduced impulsive and unsystematic problem-solving behaviors and replaced them with more deliberate and organized cognitive activity. According to the metacognitive perspective, successful problem solving depends not merely on possessing mathematical knowledge but also on knowing when and how to use that knowledge effectively (1). Students who learn to ask themselves questions such as "What is this problem asking?", "What strategy is appropriate?", "Is my current approach working?", and "Does this answer make sense?" may become less dependent on trial-and-error procedures and more capable of regulating the solution process. In this way, metacognitive training can transform problem solving from a passive response to mathematical demands into an active process of strategic decision making.

The present findings are also consistent with the Regulated Attention in Mathematical Problem Solving framework, which emphasizes that mathematical performance depends on the effective allocation and regulation of cognitive resources (4). Mathematical problems often place substantial demands on working memory and sustained attention. When students lack metacognitive control, cognitive resources may be consumed by irrelevant information, uncertainty, anxiety, or repeated use of ineffective strategies. Metacognitive instruction can help learners recognize when their attention has shifted away from relevant information and redirect cognitive resources toward the task. The ability to stop, reconsider, and adjust a strategy may therefore improve both accuracy and efficiency. The significant and sustained improvement in problem-solving performance observed in this study may reflect the gradual internalization of these regulatory processes.

The results are also supported by research on mathematical beliefs and metacognitive functioning. Suliani and colleagues found that students' mathematical beliefs were related to their metacognitive skills during problem solving, indicating that successful mathematical functioning involves both cognitive regulation and students' beliefs about the nature of mathematics and their own capacity to engage with it (6). Metacognitive training may gradually alter students' perceptions of mathematical problems by helping them understand that successful solutions can be constructed through systematic strategies rather than depending solely on immediate insight or fixed ability. This shift may encourage greater persistence and deeper engagement when students face difficult problems. Similarly, Tsampouris and Requena demonstrated the value of metacognitive strategies in logical-mathematical thinking, showing that structured regulatory strategies can facilitate reasoning even among adolescents experiencing attentional difficulties (16). Together, these studies provide strong support for the improvement in problem-solving performance found in the present research.

The second major finding was that metacognitive mathematics training significantly improved self-regulated learning. Students in the experimental group demonstrated a marked increase from pretest to posttest, and this improvement remained evident at follow-up. This finding is consistent with the theoretical assumption that metacognition represents a central component of self-regulated learning. Self-regulation requires students to establish goals, plan learning activities, monitor comprehension, regulate effort, modify ineffective strategies, and evaluate outcomes. Metacognitive training directly targets many of these processes and therefore provides students with practical tools for taking greater control of their learning. Rashidi and colleagues found that training cognitive and metacognitive self-regulated learning strategies improved students' academic functioning, including self-efficacy and motivation (17). Taghani and Razavi similarly reported that metacognitive study-strategy training enhanced academic engagement, performance, and self-efficacy, highlighting the broader regulatory benefits of metacognitive instruction (18).

The improvement in self-regulated learning can be explained by the active structure of the training sessions. Students were not simply taught specific mathematical content; rather, they were encouraged to assume responsibility for managing the process through which they learned and solved problems. Planning exercises strengthened the ability to organize learning before acting, monitoring prompts encouraged ongoing evaluation of comprehension and performance, and reflective activities promoted evaluation after task completion. These processes closely correspond to the cyclical structure of self-regulated learning, in which planning, performance monitoring, and self-reflection continually influence one another. Repeated practice of these strategies during mathematics activities may have helped students generalize them to broader academic learning situations.

The findings of Yunus and colleagues also support this interpretation. Their study demonstrated meaningful relationships among metacognitive awareness, achievement motivation, attitudes, and problem-solving ability, suggesting that self-regulatory competence develops through the interaction of cognitive and motivational factors (7). Similarly, Mam-Sharifi and colleagues showed that problem-solving strategies can mediate relationships involving metacognitive beliefs and adaptive functioning (8). These findings imply that when learners develop awareness of how they approach problems and how they can modify their cognitive strategies, they may become more capable of regulating not only a single task but their overall learning behavior. The persistence of self-regulated learning gains at follow-up in the present study may therefore indicate that students acquired transferable regulatory skills rather than only temporary task-specific techniques.

The third major finding was that metacognitive mathematics training significantly increased mathematical self-efficacy. Students who participated in the intervention reported substantially greater confidence in their mathematical capabilities at posttest, and this improvement remained stable at the follow-up assessment. This result is consistent with studies showing a close relationship between metacognition and self-efficacy. Tak and colleagues found that metacognitive awareness mediated the relationship between self-efficacy and mathematical reasoning, indicating that students' perceived competence and their ability to regulate cognition are interdependent (9). Fitri and colleagues similarly showed that metacognition can mediate the effect of self-efficacy on problem-solving performance (10). These findings suggest that self-efficacy may be strengthened when students develop more effective control over the cognitive processes involved in solving difficult problems.

A plausible explanation for this finding is that metacognitive training created repeated mastery experiences. As students learned to decompose complex problems, select appropriate strategies, monitor their performance, and correct errors, they were more likely to experience success on tasks that they previously perceived as difficult. Repeated successful experiences may gradually strengthen beliefs about personal competence. Instead of attributing successful performance to chance or unusually easy tasks, students may begin to understand that their success results from strategies that they themselves can intentionally apply. This perception of controllability is important for self-efficacy because confidence is more likely to increase when learners attribute achievement to effective actions within their own control.

The relationship between metacognitive beliefs and academic self-efficacy reported in Iranian samples further supports the present findings. Karimi and colleagues identified a meaningful relationship between metacognitive beliefs and academic self-efficacy among students in Tehran, highlighting the contribution of cognitive regulation to students' confidence in academic contexts (11). Kamyabi and colleagues also demonstrated the importance of metacognitive beliefs in a model involving self-efficacy and academic procrastination (12), while Kamyabi Mitra and colleagues similarly emphasized the mediating role of metacognitive beliefs in relationships among self-efficacy, perfectionism, and maladaptive academic behavior (13). These studies collectively indicate that students' interpretations of their own cognitive functioning may influence how capable they feel in academic tasks. The present intervention may therefore have increased mathematical self-efficacy by giving students a clearer sense of how to manage cognitive demands successfully.

The present finding regarding mathematical self-efficacy is also consistent with intervention research. Shoaei and colleagues showed that metacognitive strategy training could improve academic self-efficacy while reducing test anxiety among secondary-school students (19). Taghani and Razavi likewise reported improvements in self-efficacy following metacognitive skills training (18). In addition, Honelly found that an instructional environment designed to promote active engagement was associated with improvements in self-efficacy and metacognitive awareness (20). Although these interventions differ in content and structure, they share an emphasis on active learner involvement, strategic awareness, and greater responsibility for learning. Such characteristics may strengthen self-efficacy because students become more aware of specific strategies they can employ when difficulties arise.

The interaction between metacognition, self-efficacy, and emotional responses may also be relevant. Nourozzade and Soleimani identified structural relationships among metacognitive awareness, self-efficacy, academic motivation, attitudes toward mathematics, and mathematical anxiety in students with learning disabilities (15). Mathematics anxiety can impair performance by consuming working-memory resources and encouraging avoidance. When students develop metacognitive strategies, they may become better able to interpret difficult tasks as manageable challenges rather than as threats. This can reduce cognitive disorganization and strengthen perceived competence. Afshari and colleagues similarly demonstrated that metacognitive training was effective in reducing mathematics-related problems among students with learning disorders (14). The current findings extend this evidence by showing that structured metacognitive mathematics training can simultaneously affect performance, self-regulation, and perceived competence among secondary-school students.

The motivational implications of the findings should also be considered. Moustakas and Gonida demonstrated that high achievement in mathematics is associated with distinct motivational profiles that are linked with metacognitive processes and achievement emotions (21). This suggests that metacognitive competence may help organize the motivational and emotional conditions that support persistence in mathematics. Students who understand how to respond strategically to difficulty may be less likely to interpret temporary failure as evidence of inability and more likely to remain engaged. Thus, the improvement in self-efficacy observed in the present study may have been reinforced by improvements in problem-solving competence and self-regulated learning, creating a mutually supportive pattern in which improved regulation produces successful experiences, successful experiences strengthen self-efficacy, and stronger self-efficacy encourages further strategic engagement.

The maintenance of intervention effects at the two-month follow-up is particularly important. The nonsignificant differences between posttest and follow-up scores suggest that the benefits of the intervention were not limited to the immediate training period. This stability may be attributable to the transferable nature of metacognitive strategies. Unlike highly specific procedural instruction, metacognitive strategies can be applied across different tasks and contexts. Once students internalize processes such as planning, self-questioning, monitoring, and evaluation, these strategies can continue to be used independently after formal training has ended. The follow-up results therefore strengthen the argument that metacognitive mathematics training may contribute to relatively durable changes in students' approaches to mathematics rather than producing only short-term performance gains.

The present study had several limitations that should be considered when interpreting the findings. First, the sample consisted of only 30 secondary-school students from Tehran, which limits the generalizability of the results to students from other educational levels, geographical regions, socioeconomic backgrounds, or school systems. Second, although the study included a control group and a follow-up assessment, the follow-up period was limited to two months and therefore does not establish whether the observed changes would remain stable over longer periods. Third, self-regulated learning and mathematical self-efficacy were assessed primarily through self-report instruments, which may be influenced by social desirability, response tendencies, or participants' subjective interpretations of their own behavior. Fourth, the intervention was conducted as a structured program in addition to regular mathematics instruction, and therefore instructor characteristics, group dynamics, and students' awareness of participation in a special training program may have contributed to the observed effects. Finally, the relatively small sample size restricted the possibility of examining whether the effectiveness of metacognitive mathematics training varied according to demographic, academic, or individual-difference variables.

Future studies should replicate the present research with larger and more diverse samples drawn from different schools, educational districts, age groups, and academic levels in order to evaluate the generalizability of the findings. Longer follow-up periods, such as six months or one academic year, would be valuable for determining the durability of changes in problem-solving performance, self-regulated learning, and mathematical self-efficacy. Researchers could also compare metacognitive mathematics training with other instructional approaches, such as problem-based learning, cooperative learning, self-regulated learning training, or technology-assisted mathematics instruction, rather than using only a no-treatment control group. Future studies should incorporate behavioral observations, think-aloud protocols, teacher ratings, mathematics achievement records, and process-based assessments in addition to self-report measures. It would also be useful to investigate potential mediating and moderating mechanisms, including mathematics anxiety, working memory, achievement motivation, prior mathematics performance, perfectionism, and academic engagement, to clarify how and for whom metacognitive mathematics training produces the strongest effects.

The findings suggest that metacognitive strategies should be incorporated systematically into mathematics instruction rather than being treated as supplementary skills taught only when students experience academic difficulty. Mathematics teachers can explicitly model how to analyze a problem, plan a strategy, monitor progress, identify errors, compare alternative methods, and evaluate the reasonableness of an answer. Classroom activities should provide students with opportunities to explain how they reached a solution rather than focusing exclusively on whether the final answer is correct. Teachers can also use reflective questions, learning journals, self-monitoring checklists, peer explanations, and guided error analysis to strengthen students' awareness of their own learning processes. Schools may benefit from professional development programs that equip mathematics teachers with practical methods for integrating metacognitive instruction into routine lessons. Particular attention should be given to students who demonstrate low confidence, repeated avoidance of difficult mathematics tasks, weak persistence, or ineffective study habits, because these students may benefit substantially from structured training that helps them experience greater control over mathematical learning.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adhered in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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