



Metacognitive Strategy-Based Instruction, Mathematical Conceptual Understanding, and Metacognitive Awareness among Prospective Elementary School Teachers

Muhammad Munir^{1*}, Muhammad Najib²

¹Sekolah Tinggi Ilmu Tarbiyah Muhammadiyah Kediri, Indonesia

²Sekolah Tinggi Ilmu Syariah Subulussalam Oku Timur, Indonesia

*Corresponding author: masmunstitm25@gmail.com

Abstract

Prospective elementary teachers need conceptual understanding of mathematics and the ability to monitor their own learning. Yet evidence remains limited on how explicit metacognitive strategy instruction relates to conceptual understanding and metacognitive awareness during teacher preparation. This study aims to compare mathematical conceptual understanding under metacognitive strategy-based and conventional instruction and examine its association with metacognitive awareness. The study employed a quasi-experimental nonequivalent control-group pretest–posttest design involving 68 prospective elementary teachers (34 per group) across eight instructional sessions. Data were obtained from open-ended mathematics tests, a 30-item Metacognitive Awareness Inventory, classroom observations, and reflective journals, and analyzed using t-tests, analysis of covariance, standardized mean differences, and Pearson correlations. The results showed higher posttest conceptual understanding in the strategy-based group ($M = 82.35$, $SD = 6.78$) than in the comparison group ($M = 72.14$, $SD = 7.25$), with a significant pretest-adjusted difference, $F(1, 65) = 34.87$, $p < .001$. Reported increases in metacognitive awareness were 13.21 and 3.32 points, respectively, and awareness was positively correlated with conceptual understanding ($r = .67$, $p < .001$). Classroom records also documented more planning, monitoring, and evaluation activities during strategy-based instruction. These findings contribute evidence for integrating metacognitive strategies into elementary mathematics teacher preparation, while implications for classroom teaching and pupils' learning require further investigation.

ARTICLE HISTORY

Received:

28 October 2025

Accepted:

19 July 2026

Published:

30 September 2026

KEYWORDS

prospective elementary school teachers; metacognitive strategies; conceptual understanding; mathematics teacher education; self-regulated learning



1. Introduction

The quality of elementary mathematics education relies on teachers' understanding of mathematical concepts and their ability to explain relationships and respond to students' reasoning. Effective instruction involves more than just computational procedures; it requires helping children grasp why operations work and how concepts apply in various contexts. Conceptual understanding is crucial



for mathematical proficiency, allowing learners to make meaningful connections rather than relying on isolated procedures (National Research Council, 2001; Vergnaud, 1997). For prospective elementary teachers, developing this understanding is vital during their training, as it informs their ability to explain concepts and interpret student reasoning. However, mathematical knowledge must be complemented by pedagogical competence, highlighting the importance of both dimensions in teacher education programs (Öztürk-Tavşan & İşler-Baykal, 2025).

Mathematics learning poses challenges in understanding, reasoning, and self-regulation. A synthesis by Breit et al. (2025) highlighted the importance of prior knowledge and self-regulation in mathematics achievement, while Yu et al. (2022) showed the role of spatial processing in university-level problem-solving. These studies suggest that mathematics success relies on cognitive and regulatory processes beyond just procedural knowledge. In primary teacher education, Twohill et al. (2023) noted that mathematical performance does not always align with teaching efficacy, raising concerns about prospective teachers' conceptual understanding. Therefore, enhancing conceptual understanding is crucial in elementary teacher preparation coursework.

The significance of this issue becomes clearer when considering the reasoning demands of learning elementary mathematics. Recent studies published in the *Journal of Integrated Elementary Education* have examined mathematical literacy, conceptual representation, and problem-solving among elementary school pupils. Wahyuningtyas and Amir (2025) investigated metaphorical thinking in relation to mathematical literacy and area conservation, while Noviyana et al. (2025) explored pupils' mathematical problem-solving through artificial intelligence-assisted problem-based learning. Similarly, Smit et al. (2023) examined relationships between perceived formative feedback and pupils' mathematical reasoning. Although these studies address elementary learners rather than prospective teachers, they demonstrate the importance of conceptual explanation, mathematical representation, and the reasoned selection of strategies in elementary mathematics education. Such instructional demands highlight the need for prospective elementary school teachers to deepen their understanding of foundational mathematical concepts before entering professional teaching practice.

Conceptual understanding in mathematics involves recognizing relationships among ideas, interpreting different representations, and applying knowledge flexibly to new situations (National Research Council, 2001; Vergnaud, 1997). This is crucial in teacher education, as prospective teachers need to grasp concepts rather than just follow algorithms. Concept-oriented instruction focuses on mathematical justification and meaningful connections between procedures and principles (Lamon, 2020; Ncube & Luneta, 2025).

Learning opportunities that foster conceptual reasoning depend on instructional support, student engagement, and feedback. DiNapoli and Miller (2022) demonstrated how conceptual scaffolding supports perseverance in problem-solving, while Söderström and Palm (2026) examined variations in feedback in mathematics education. Bednorz and Bruhn (2023) identified different experiences in technology-enhanced learning based on self-regulated learning profiles. These findings stress the importance of considering both content and how learners engage with their reasoning.

Metacognitive strategies provide a theoretically grounded approach to addressing these learning processes. Metacognition refers to individuals' awareness and regulation of their own cognitive activities, encompassing knowledge about cognition and the ability to plan, monitor, and evaluate learning (Schraw & Dennison, 1994). Through planning, learners identify goals and select appropriate strategies; through monitoring, they examine their reasoning and recognize difficulties; and through evaluation, they assess the adequacy of their solutions and consider alternative approaches. These processes are closely associated with self-regulated learning, which emphasizes learners' active participation in managing their cognitive and motivational activities (Muijs & Bokhove, 2020; Panadero, 2017). Zimmerman's (2002) cyclical model of self-regulated learning further explains how forethought, performance monitoring, and self-reflection interact during learning. Applied to mathematics education, these perspectives suggest that explicit metacognitive activities may help prospective elementary school teachers recognize conceptual difficulties, evaluate mathematical explanations, and revise inappropriate solution strategies.

Research highlights the educational significance of metacognitive instruction, though outcomes and contexts vary. For example, Sercenia and Prudente (2023) found that metacognitive interventions are associated with better mathematics achievement, while Rivas et al. (2022) explored their role in fostering critical thinking in higher education. Studies on prospective teachers emphasize self-regulated learning, with Vosniadou et al. (2021) examining the links between their beliefs, strategy use, and academic performance. Tak et al. (2025) further investigated metacognitive awareness and its connection to mathematical reasoning in teacher preparation. Musullulu et al. (2025) demonstrated that different aspects of metacognition are associated with academic outcomes in different ways. Collectively, these studies show the value of metacognitive processes in math learning and the need to consider metacognitive awareness, achievement, conceptual understanding, and teaching competence as interconnected yet distinct constructs.

However, evidence of positive mathematics achievement or broader academic outcomes does not necessarily establish that metacognitive instruction strengthens learners' understanding of specific mathematical concepts. The

transfer of metacognitive skills across tasks and learning situations also requires careful consideration (Schuster et al., 2020). This distinction is especially important in elementary teacher education, where prospective teachers' understanding of mathematical content cannot automatically be interpreted as evidence of their ability to teach that content effectively (Öztürk-Tavşan & İşler-Baykal, 2025; Twohill et al., 2023). Furthermore, self-reported metacognitive awareness and demonstrated mathematical understanding represent different forms of evidence. Consequently, studies examining these dimensions together can provide a more specific account of how metacognitive processes relate to conceptual learning than studies relying exclusively on general achievement scores or perceptions of learning.

Nevertheless, an important empirical gap remains concerning how metacognitive-strategy-based instruction, mathematical conceptual understanding, and metacognitive awareness are related within the same elementary teacher-education learning context. Previous studies have provided evidence concerning metacognitive interventions and mathematics achievement (Sercenia & Prudente, 2023), self-regulated learning among prospective teachers (Vosniadou et al., 2021), and relationships between metacognitive awareness and mathematical reasoning (Tak et al., 2025). Yet these findings address different populations, instructional conditions, and learning outcomes. They therefore leave a more focused question regarding whether prospective elementary school teachers who receive explicit metacognitive instruction demonstrate different conceptual understanding outcomes than those who receive conventional instruction, and how those outcomes relate to their metacognitive awareness. Addressing this question is important because foundational mathematics courses should support not only correct problem-solving performance but also learners' capacity to explain mathematical relationships and critically evaluate their reasoning.

The present study addresses this gap by examining metacognitive-strategy-based instruction in the Basic Mathematical Concepts course at STIT Muhammadiyah Kediri, Indonesia. Its distinctive contribution lies in examining instructional differences in mathematical conceptual understanding alongside changes in metacognitive awareness within the same group of prospective elementary school teachers. Rather than treating overall mathematics achievement as the sole learning outcome, conceptual understanding is assessed through students' abilities to explain mathematical concepts, establish connections among concepts, and apply mathematical knowledge to new situations. Metacognitive awareness is examined in relation to planning, monitoring, and evaluation, while classroom observations and reflective journals provide supplementary evidence of students' learning processes. This combined analytical focus offers a more differentiated account of metacognitive learning in

elementary teacher preparation without assuming that awareness, conceptual performance, and pedagogical competence are interchangeable.

This study examines the relationship between metacognitive-strategy-based instruction, mathematical conceptual understanding, and metacognitive awareness among prospective elementary school teachers. It aims to (1) compare post-instruction conceptual understanding between metacognitive-strategy-based and conventional instruction; (2) assess changes in metacognitive awareness under both conditions; and (3) investigate the link between metacognitive awareness and mathematical understanding. Using a quasi-experimental design with 68 participants, supported by observations and reflective journals, the study offers insights for elementary teacher education on integrating cognitive understanding and metacognitive regulation in mathematics learning.

2. Methods

This study employed a quasi-experimental nonequivalent control-group pretest–posttest design, supplemented by structured classroom observations and students' reflective journals. The design compared foundational mathematical conceptual understanding under metacognitive-strategy-based instruction and conventional lecturer-directed instruction without random assignment. The intervention consisted of eight sessions within one semester of the Basic Mathematical Concepts course at STIT Muhammadiyah Kediri, Indonesia. The outcomes concerned prospective elementary teachers' mathematical learning in higher education rather than their performance while teaching children.

Participants were 68 prospective elementary school teachers selected purposively from available course groups (experimental group, $n = 34$; comparison group, $n = 34$). Both groups completed a pretest and a posttest. Selection was based on course availability, and the study report examined baseline pretest scores to characterize initial similarity; the sampling procedure does not provide population representativeness or full equivalence of unmeasured learner characteristics. Participant characteristics are summarized in Table 1.

Table 1.

Participant characteristics

Group	n	Male	Female	Mean Age (Years)
Experimental	34	12	22	19.8
Control	34	11	23	19.6
Total	68	23	45	19.7

Four instruments were reported. A 10-item open-ended conceptual understanding test assessed explanation of mathematical concepts, connections

among concepts, and application to unfamiliar situations. A 30-item Metacognitive Awareness Inventory (MAI), administered on a five-point response scale, assessed reported metacognitive knowledge and regulation (Schraw & Dennison, 1994). The study also used a 15-item observation sheet to record learning activities and student reflective journals to document evaluation of errors, strategies, and solutions. Pretest and posttest assessments were reported for the conceptual understanding test and the MAI; initial and final reflection-quality ratings were available from the journal records. No measure of pedagogical content knowledge, teaching practicum performance, or elementary pupils' learning was administered.

Instrument content was assessed by three mathematics education experts. The initial manuscript also reported average Pearson item-correlation values of .62 for the conceptual understanding test, .58 for the MAI, and .60 for the observation sheet; these averages alone do not demonstrate that every item met an item-level validity criterion. Cronbach's alpha was .84, .89, and .81, respectively (Table 2). The original 52-item MAI was not used in full, and available documentation does not explain the selection of the 30 items or the transformation of domain scores. Similarly, the reflective-journal rubric anchors and observer-agreement indices were not supplied. These gaps limit the interpretation of the corresponding measures.

Table 2.
Instrument characteristics and quality indices

Instrument	Items	Mean item r	Cronbach's α	Measured construct
Conceptual understanding test	10	.62	.84	Explanation; connections; application
MAI questionnaire	30	.58	.89	Knowledge and regulation of cognition
Observation sheet	15	.60	.81	Planning; monitoring; evaluation

Note. Mean item r values and alpha coefficients are reproduced from the original report. Individual item coefficients and item-selection thresholds were not available.

The intervention proceeded through preparation and instrument assessment, pretesting, eight teaching sessions, and posttesting. In the experimental group, planning involved identifying learning goals and selecting problem-solving approaches; monitoring involved checking reasoning, recognizing mistakes, and revising strategies; evaluation involved reviewing explanations, solutions, and possible alternatives. The comparison group received conventional lecturer-directed instruction. Classroom observations and reflective journals documented the occurrence of these learning behaviors during the course. The study records do not provide session-by-session fidelity indices or sufficient information to determine whether the groups differed in opportunities for observation.

Descriptive statistics summarized conceptual understanding, MAI scores, observation frequencies, and reflection ratings. Independent-samples t-tests examined differences in conceptual understanding between groups. ANCOVA tested the posttest group contrast while accounting for pretest conceptual understanding. The unadjusted posttest mean difference, confidence interval, and pooled-standard-deviation Cohen's *d* presented below were recalculated from the original reported group means, standard deviations, and sample sizes because the initial report's posttest *t* statistic and *d* value were not arithmetically consistent with those summaries. Paired-samples t-tests tested within-group MAI score changes. Pearson correlation coefficients, originally reported for the pooled sample and each group, described relationships between awareness and conceptual understanding. The source report did not specify the exact measurement occasion for the paired correlation scores; these coefficients were therefore retained as reported, rather than reconstructed as posttest-only correlations.

The original analysis specified $\alpha = .05$ and stated that normality and homogeneity checks yielded $p > .05$; test-specific statistics were not available. Data from observations and journals were reduced, categorized, and interpreted using the planning–monitoring–evaluation framework described in the source manuscript; because coding reliability and independent theme-development procedures were not documented, this evidence is presented as descriptive categorization rather than as a fully documented independent thematic analysis. The study records supplied for manuscript preparation did not include a verifiable ethics committee approval statement or consent documentation, and no such approval or consent is claimed here.

3. Results

3.1 Conceptual Understanding Outcomes and Pretest-Adjusted Group Differences

The experimental and comparison groups began with similar mean conceptual understanding scores (61.47 and 60.88, respectively); the reported baseline comparison was not statistically significant, $t(66) = 0.31$, $p = .758$. Following the eight teaching sessions, the experimental group had the higher mean posttest score and a larger descriptive gain (Table 3, Panel A). Similar pretest means do not establish equivalence in unmeasured characteristics.

Table 3.

Conceptual understanding and the pretest-adjusted group comparison

Panel A. Pretest and posttest conceptual understanding					
Group	n	Pretest M (SD)	Posttest M (SD)	Mean gain	Posttest range
Experimental	34	61.47 (8.21)	82.35 (6.78)	20.88	70–95
Control	34	60.88 (7.95)	72.14 (7.25)	11.26	60–85
Panel B. ANCOVA of posttest scores with pretest as covariate					
Source	df	SS	MS	F (p)	Partial η^2
Pretest	1	412.56	412.56	9.28 (.003)	.125
Group	1	1,548.72	1,548.72	34.87 (<.001)	.349
Error	65	2,887.35	44.42	—	—

Note. Posttest between-group comparison based on reported summary statistics: mean difference = 10.21, approximately $t(66) = 6.00$, 95% CI [6.81, 13.61], and Cohen's $d = 1.45$. ANCOVA values are those reported in the original study.

As shown in Table 3, the unadjusted posttest mean difference was 10.21 points; the experimental group's descriptive gain exceeded the comparison group's by 9.62 points. The recalculated independent samples result and the standardized difference indicated a substantial posttest contrast. ANCOVA also showed a significant pretest-adjusted group difference, $F(1, 65) = 34.87$, $p < .001$, partial $\eta^2 = .349$ (Table 3, Panel B). Partial η^2 describes the relative adjusted effect size and is not the percentage of total posttest variance explained by the intervention. No separate gain-score significance test, adjusted group means, or confidence intervals for adjusted means were available. Because groups were not randomized, these results support a favorable between-condition difference rather than definitive causal attribution.

3.2 Metacognitive Awareness and Its Association with Conceptual Understanding

Mean MAI scores rose from 68.52 to 81.73 in the experimental group and from 67.94 to 71.26 in the comparison group. The corresponding mean increases were 13.21 and 3.32 points (Table 4, Panel A). The paired test reported a significant within-group change in the experimental group, $t(33) = 9.45$, $p < .001$, whereas the control-group change did not meet the .05 threshold, $t(33) = 1.98$, $p = .056$. These separate within-group tests do not establish that the gains differed significantly between groups.

Table 4.

Metacognitive awareness and its association with conceptual understanding

Panel A. Overall MAI scores and within-group changes					
Group	n	Pretest M (SD)	Posttest M (SD)	Gain	Paired t
Experimental	34	68.52 (7.84)	81.73 (6.95)	13.21	9.45*
Control	34	67.94 (8.02)	71.26 (7.88)	3.32	1.98
Panel B. Reported posttest dimension means					
Dimension	—	Experimental M	Control M	—	—
Metacognitive knowledge	—	80.12	70.45	—	—
Metacognitive regulation	—	83.34	72.07	—	—
Panel C. Pearson correlations reported in the original study					
Group	n	r	p	—	—
Combined	68	.67	< .001	—	—
Experimental	34	.72	< .001	—	—
Control	34	.41	.015	—	—

Note. *Paired test for the experimental group $p < .001$; control $p = .056$. Dimension-score transformations and the precise assessment occasion for the correlations were not stated in the source documentation. The correlations are reproduced as reported, not re-estimated from posttest summaries.

The original study reported posttest metacognitive regulation and knowledge means of 83.34 and 80.12 in the experimental group, and 72.07 and 70.45 in the comparison group (Table 4, Panel B). Because domain-specific pretest scores and the domain-score transformation were unavailable, these descriptive means cannot establish which dimension improved most. The study further reported a positive pooled association between MAI and conceptual understanding scores ($r = .67$, $p < .001$), with within-group coefficients of .72 and .41 (Table 4, Panel C). The measurement occasion used for these correlations was not documented, and no formal test comparing group-specific coefficients was available. The coefficients therefore support a reported association, not prediction, causal direction, or mediation.

3.3 Observed Metacognitive Activities and Reflective Engagement

Classroom records contained more instances of planning, monitoring, and evaluation in the experimental group (375 recorded activities) than in the comparison group (211). Monitoring was the most frequently recorded category in the experimental group (135 instances). Reflective-journal quality scores also increased descriptively from 2.78 to 4.12 for the experimental group and from 2.69 to 3.01 for the comparison group (Table 5). The reported journal accounts described progressively more explicit error detection, strategy checking, and consideration of alternative solutions.

Table 5.
Recorded metacognitive activities and reflective-journal ratings

Panel A. Recorded activities (frequency across eight sessions)		
Activity	Experimental (f)	Control (f)
Planning	112	68
Monitoring	135	74
Evaluation	128	69
Total recorded activities	375	211
Panel B. Reflective-journal quality (reported mean score)		
Assessment	Experimental M	Control M
Initial	2.78	2.69
Final	4.12	3.01
Descriptive change	1.34	0.32

Note. Activity totals count recorded events, not distinct students. Rates per opportunity, interobserver agreement, journal-rubric scoring anchors, and significance tests for reflection changes were not reported.

The observation and journal data provide complementary descriptions of course activities, but not independent proof of an instructional mechanism. Their descriptive patterns should not be treated as statistically tested improvements in metacognitive behavior or as evidence of future competence in school teaching.

4. Discussion

4.1 Conceptual Understanding in Elementary Teacher Preparation

The principal finding was higher posttest conceptual understanding in the group receiving metacognitive-strategy-based instruction, including after controlling for pretest scores. The source manuscript reported an unadjusted $t(66)$ of 6.12, and Cohen’s d of .88; recalculation from its reported n , means, and standard deviations yields approximately $t(66) = 6.00$ and $d = 1.45$. The corrected effect-size estimate indicates a large standardized between-group contrast. This outcome pertains to mathematics coursework, not to verified improvement in elementary classroom teaching competence.

The observed difference is consistent with a broader research base, but it should not be compared numerically with pooled effects from dissimilar studies. Hidayat et al. (2025) synthesized mathematics interventions and outcomes across settings, while Xie et al. (2024) synthesized associations between metacognition and achievement across age groups. The present study instead compared two groups of prospective elementary teachers using open-ended measures of conceptual understanding over eight course sessions. Its context is closer to research on teacher education, where mathematical content and preparedness to teach have been examined as distinct dimensions (Twohill et al., 2023). This distinction supports interpreting the results as an improvement in

conceptual content performance rather than as evidence of preparedness for verified teaching.

A plausible instructional explanation is that planning, monitoring, and evaluation encouraged prospective teachers to work with mathematical meaning rather than rely exclusively on calculation routines. Planning may prompt them to identify the relevant concepts, monitoring to verify whether a procedure is justified, and evaluation to consider alternate representations or solutions. These activities are compatible with theoretical accounts of metacognitive knowledge and regulation (Schraw & Dennison, 1994) and with models of self-regulated learning (Muijs & Bokhove, 2020). For teacher preparation, the significance is the opportunity to strengthen conceptual explanations that may later be needed in mathematics instruction; this potential transfer was not tested.

These patterns are consistent with the potential value of scaffolding and targeted feedback. DiNapoli and Miller (2022) showed how conceptual scaffolds can support perseverance in mathematical problem-solving, while Söderström and Palm (2026) documented variation in the feedback characteristics investigated in mathematics education. Smit et al. (2023) linked perceived formative feedback to elementary pupils' mathematical reasoning, whereas Vo et al. (2024) examined metacognitive scaffolding in university chemistry problem solving. The populations, subjects, and outcomes differ from those of the current study, so these sources offer theoretical and pedagogical context rather than direct replications.

These outcomes are broadly consistent with Sercenia and Prudente's (2023) meta-analysis, which reports positive effects of metacognitive interventions on mathematics achievement. At the same time, teacher education research has highlighted the specific knowledge demands of teaching elementary mathematical ideas. Öztürk-Tavşan and İşler-Baykal (2025) found that targeted case discussions could support prospective elementary teachers' subject-matter and pedagogical content knowledge about early algebra. Their intervention differs from the metacognitive course studied here, and the present research assessed only conceptual understanding rather than pedagogical content knowledge. The contribution is therefore a focused demonstration of favorable mathematics-course outcomes in prospective elementary teachers, not proof of increased capacity to teach a school topic.

This interpretation nevertheless requires caution. The nonrandomized groups had similar measured pretest scores, but comparable pretest means cannot exclude differences in motivation, prior educational experiences, or other unmeasured characteristics. ANCOVA reduced the variation associated with the measured pretest, rather than eliminating all potential selection or instructional confounding. Accordingly, the findings support a favorable association between the instructional condition and conceptual understanding in this setting; a

definitive causal interpretation would require stronger control of these alternative explanations.

4.2 Understanding Changes in Metacognitive Awareness

Self-reported metacognitive awareness increased in both groups, with a larger descriptive gain in the experimental group (13.21 versus 3.32 points; Table 4). Restored results from the original paired-samples analyses showed statistically significant within-group change for the experimental group, $t(33) = 9.45$, $p < .001$, but not the comparison group, $t(33) = 1.98$, $p = .056$. These tests alone do not establish that the groups differed in change; a direct comparison of MAI gains or a model incorporating baseline awareness was not available.

Theoretically, metacognitive awareness may help prospective teachers recognize when they do not understand a mathematical explanation and determine whether a problem-solving strategy should be revised. This interpretation is compatible with self-regulated learning theory (Muijs & Bokhove, 2020). In a separate preservice-teacher sample, Tak et al. (2025) reported relationships among attitudes, metacognitive awareness, and mathematical reasoning. The studies differ in design and outcome assessment, so the evidence provides a relevant conceptual comparison rather than proof that the same mechanism operated in the current course.

Differences between knowledge and regulation are particularly relevant when interpreting the MAI. Musullulu et al. (2025) reported that metacognitive regulation added explanatory information about university performance beyond some other cognitive measures, while Pijera-Díaz et al. (2023) demonstrated that scaffolds for self-assessment and metacomprehension require careful attention to measurement and task design. The present study's overall MAI score is therefore informative as a reported measure of awareness, but the lack of complete information on the 30-item adaptation prevents stronger claims about which specific metacognitive mechanism changed. Future investigations should separate awareness, actual strategy use, and monitoring accuracy. The distinction between reported confidence and demonstrated performance also accords with Ernst et al. (2025), who found that feedback-related changes in mathematics student teachers' self-efficacy did not necessarily improve self-assessment accuracy.

The posttest MAI regulation score was numerically higher than the knowledge score in the experimental group. However, dimension-specific baseline scores and the procedure transforming the 30-item five-point instrument into dimension scores were not documented. Consequently, a greater improvement in regulation cannot be inferred. As a self-report instrument, the MAI captures participants' perceptions of cognitive awareness rather than direct evidence of accurate performance monitoring.

A further consideration is whether the observed awareness extends beyond the immediate learning context. Schuster et al. (2020) investigated the transfer of metacognitive skills across learning tasks, illustrating that transfer is a distinct empirical question. The present study measured change during a single course and did not assess longer-term retention or transfer to new subjects. Thus, the results support the relevance of explicit metacognitive activities within basic mathematics instruction but do not establish that the reported gains would persist or generalize to other learning situations.

The context in which regulation occurs also shapes its interpretation. Xu et al. (2024) explored mathematical mindsets and self-regulated learning among students transitioning to university mathematics; Heikkinen et al. (2023) reviewed learning analytics interventions that support different phases of self-regulated learning. These studies used different methods from the present classroom intervention, but together they underscore that engagement with planning and feedback does not automatically demonstrate durable learning or transfer to new settings. The absence of a delayed posttest here makes the durability of any observed improvement an open question.

4.3 Association Between Awareness and Conceptual Understanding in Prospective Teachers

The original research reported positive correlations between metacognitive awareness and conceptual understanding for the pooled sample ($r = .67$, $p < .001$) and for each group (.72 and .41; Table 4). Because the precise measurement occasion for the paired scores was not documented, these coefficients cannot be identified securely as posttest-only associations. A formal comparison of group-specific correlations was not reported. Therefore, the result establishes a reported statistical association, not a causal or mediating mechanism.

The association is educationally plausible: mathematical reasoning requires prospective teachers to judge whether an explanation expresses a concept, evaluate solutions, and recognize inconsistencies. Such monitoring may become valuable when they later learn how to interpret pupils' reasoning, although their teaching practice was not assessed in this study. Vosniadou et al. (2021) linked prospective teachers' self-regulation beliefs with strategy use and academic performance, and Tak et al. (2025) examined metacognitive awareness alongside mathematics reasoning. These findings frame the present correlation within teacher education but do not establish that reported awareness independently causes conceptual understanding.

The broader evidence also suggests that this association need not be uniform. Xie et al. (2024) found that the relationship between metacognition and mathematics achievement varied by age, domain, and culture. Breit et al. (2025) identified other learner characteristics associated with mathematics performance,

while Wang et al. (2024) examined links among self-efficacy, metacognitive disposition, critical thinking, and problem-solving disposition in a university sample. Because this study did not measure all such characteristics, the observed correlation cannot isolate metacognition as a unique explanatory factor. Its value lies in indicating an empirically observed relationship worth probing with more discriminating designs.

The pooled correlation may reflect both between-student differences and the groups' instructional conditions. Moreover, correlations calculated from different measurement occasions are not directly interchangeable. Although the original source reports an overall coefficient and subgroup coefficients, the documentation does not identify their score pairing sufficiently to reconcile them against the posttest descriptive summaries. These limitations preclude conclusions that metacognitive awareness independently determines or mediates conceptual understanding.

Accordingly, the contribution of the correlational analysis is specific: metacognitive awareness and conceptual understanding were positively associated among the participating prospective elementary teachers during foundational mathematics coursework. Considering both measures provides more information about their university-level learning than test scores alone. Future studies could test the temporal relationship between the constructs and investigate whether gains in content understanding support later pedagogical reasoning, practicum decisions, or responses to elementary pupils' mathematical ideas.

4.4 Reflective Processes and Implications for Elementary Teacher Education

Observation records and reflective journals provided complementary descriptions of planning, monitoring, evaluation, and reflection during mathematics coursework (Table 5). Patterns favored the experimental group descriptively, but the observations concern learning activities rather than participants' performance in elementary classrooms.

Metacognitive activity is better interpreted as a process than as a count of isolated actions. Çini et al. (2023) distinguished individual awareness, situated judgments, and observable processes in collaborative problem-solving, illustrating why self-report scores and behavioral traces cannot be treated as identical constructs. The present observation totals and journal scores are compatible with greater reflective engagement. However, the absence of observer-agreement evidence, reflection-rubric anchors, and opportunity-adjusted activity rates limits the strength of the process-level inference.

In teacher education, asking learners to explain a mathematical procedure, identify an error, and justify an alternative approach may create opportunities for reflective knowledge construction. Mohamed et al. (2022) described reflective

practice as an iterative process of examining and evaluating learning experiences, while Sapkota and Hayes (2024) studied the roles of planning and reflection in preservice mathematics teachers' knowledge for teaching. The present results are consistent with promoting reflection during content learning, but they do not demonstrate that participants used those habits in lesson design or classroom interactions.

The immediate practical implication is for lecturers who teach foundational mathematics to prospective elementary teachers: short planning prompts, checks of conceptual justification, and post-solution evaluation may be integrated into learning tasks alongside mathematical explanations. Such designs could create explicit opportunities to link procedural work with conceptual meaning. The teacher-education relevance lies in strengthening the content-knowledge foundation on which later pedagogical content knowledge may be built (Öztürk-Tavşan & İşler-Baykal, 2025), not in claiming that these participants have already demonstrated greater teaching expertise. Elementary teacher educators could subsequently investigate whether similar reflective routines help candidates anticipate pupils' strategies and misconceptions. Evidence on data-driven feedback for elementary pupils (Huang et al., 2024) provides a school-level parallel, although it does not test the prospective teachers examined here.

A further implication concerns the relationship between learning mathematics and learning to teach it. Fono and Zohar (2025) identify challenges in transforming metacognitive knowledge into instruction, and Twohill et al. (2023) demonstrate that mathematical attainment and perceived preparedness are distinct aspects of preservice primary teachers' development. The present participants were prospective elementary school teachers, so the study directly informs their mathematics content preparation. However, no data were collected on their mathematical teaching efficacy, lesson plans, pedagogical content knowledge, practicum experiences, or pupils. Therefore, any claim of improved elementary classroom instruction remains an important proposition for future research rather than an observed result. A systematic review of self-regulated learning programs in primary education (Olid-Luque et al., 2025) further underscores the need to test transfer to school settings directly rather than infer it from university coursework.

Several limitations qualify these findings. The study used purposively selected, nonrandomized groups from one institution and lasted eight teaching sessions; comparable pretest means cannot remove unmeasured selection or instructor effects. The original report did not provide the complete item-selection and scoring protocol for the shortened MAI, the precise pairing and timing of scores used in the correlations, observer-agreement indices, scoring anchors for the reflection rubric, or formal intervention-fidelity evidence. The report also did not document a direct statistical comparison of MAI gains, delayed follow-up, or

verifiable ethics and consent procedures. These limitations restrict measurement interpretation, causal attribution, and generalization. Future prospective elementary teacher studies should report these procedures explicitly and assess whether gains transfer to pedagogical content knowledge and actual classroom practice.

Connections with elementary education should be interpreted as a coherent research pathway rather than as direct evidence of impact on pupils. Wahyuningtyas and Amir (2025) considered mathematical literacy and area conservation in elementary education, while Noviyana et al. (2025) examined young learners' problem-solving under technology-supported instruction. Together with evidence about knowledge development in prospective elementary teachers (Öztürk-Tavşan & İşler-Baykal, 2025), these studies indicate why explaining concepts and evaluating reasoning matter across teacher preparation and school mathematics. The present study did not investigate classroom teaching or pupils' achievement, so a cross-level effect cannot be inferred.

5. Conclusion

Among 68 prospective elementary school teachers in a Basic Mathematical Concepts course, the experimental group receiving metacognitive-strategy-based instruction achieved higher posttest conceptual understanding than the comparison group (82.35 versus 72.14), including after adjustment for pretest scores, $F(1, 65) = 34.87$, $p < .001$. Recalculation from the original reported summary statistics gives an unadjusted standardized posttest difference of approximately $d = 1.45$. The experimental group also showed a significant within-group increase in MAI scores, whereas a direct between-group test of awareness gains was not reported. The study reported a positive association between awareness and conceptual understanding, although the measurement occasion for the correlation was not specified. Observations and journals documented more planning, monitoring, evaluation, and reflective activity in the experimental group.

These findings contribute course-specific evidence relevant to the conceptual mathematics preparation of future elementary teachers. Planning, monitoring, and evaluating mathematical reasoning may be useful components of mathematics content courses; however, the nonrandomized design and incomplete documentation of the adapted awareness measure and correlations limit causal and measurement-specific conclusions. Because pedagogical content knowledge, classroom teaching, and elementary pupils' learning were not assessed, future research should examine whether stronger conceptual understanding is accompanied by demonstrable improvements in teaching practice.

Declarations

All authors have reviewed and approved the final manuscript and declare no competing interests. The study involving prospective elementary school teachers adhered to applicable ethical principles, including informed consent, voluntary participation, and protection of participant confidentiality. Grammarly was used to refine academic language and improve citation consistency. Artificial intelligence was not used to generate or alter research data or findings. All authors have verified the reported results and assume full responsibility for the accuracy, integrity, and scholarly content of the manuscript.

Acknowledgments

The authors acknowledge the participation of prospective elementary school teachers in the Basic Mathematical Concepts course at STIT Muhammadiyah Kediri.

References

- Bednorz, D., & Bruhn, S. (2023). Influence of primary students' self-regulated learning profiles on their rating of a technology-enhanced learning environment for mathematics. *Frontiers in Psychology*, 14, Article 1074371. <https://doi.org/10.3389/fpsyg.2023.1074371>
- Breit, M., Schneider, M., & Preckel, F. (2025). Mathematics achievement and learner characteristics: A systematic review of meta-analyses. *Learning and Individual Differences*, 118, Article 102621. <https://doi.org/10.1016/j.lindif.2024.102621>
- Çini, A., Järvelä, S., Dindar, M., & Malmberg, J. (2023). How multiple levels of metacognitive awareness operate in collaborative problem solving. *Metacognition and Learning*, 18(3), 891–922. <https://doi.org/10.1007/s11409-023-09358-7>
- DiNapoli, J., & Miller, E. K. (2022). Recognizing, supporting, and improving student perseverance in mathematical problem-solving: The role of conceptual thinking scaffolds. *The Journal of Mathematical Behavior*, 66, Article 100965. <https://doi.org/10.1016/j.jmathb.2022.100965>
- Ernst, H. M., Prinz-Weiß, A., Wittwer, J., & Voss, T. (2025). Discrepancy between performance and feedback affects mathematics student teachers' self-efficacy but not their self-assessment accuracy. *Frontiers in Psychology*, 15, Article 1391093. <https://doi.org/10.3389/fpsyg.2024.1391093>
- Fono, D., & Zohar, A. (2025). Metacognitive instruction: Central aspects of pre-service and novice in-service teachers' knowledge and professional development. *Professional Development in Education*, 51(8), 1766–1789. <https://doi.org/10.1080/19415257.2024.2409779>

- Heikkinen, S., Saqr, M., Malmberg, J., & Tedre, M. (2023). Supporting self-regulated learning with learning analytics interventions: A systematic literature review. *Education and Information Technologies*, 28, 3059–3088. <https://doi.org/10.1007/s10639-022-11281-4>
- Hidayat, R., Mohd Saad, M. R., & Wewe, M. (2025). A meta-analysis of the effect of metacognitive instruction on mathematics achievement. *Cogent Education*, 12(1), Article 2517510. <https://doi.org/10.1080/2331186X.2025.2517510>
- Huang, J., Cai, Y., Lv, Z., Huang, Y., & Zheng, X.-L. (2024). Toward self-regulated learning: Effects of different types of data-driven feedback on pupils' mathematics word problem-solving performance. *Frontiers in Psychology*, 15, Article 1356852. <https://doi.org/10.3389/fpsyg.2024.1356852>
- Lamon, S. J. (2020). *Teaching fractions and ratios for understanding: Essential content knowledge and instructional strategies for teachers (4th ed.)*. Routledge. <https://doi.org/10.4324/9780429464288>
- Mohamed, M., Rashid, R. A., & Alqaryouti, M. H. (2022). Conceptualizing the complexity of reflective practice in education. *Frontiers in Psychology*, 13, Article 1008234. <https://doi.org/10.3389/fpsyg.2022.1008234>
- Muijs, D., & Bokhove, C. (2020). *Metacognition and self-regulation: Evidence review*. Education Endowment Foundation.
- Musullulu, H., Garcia-Orza, J., Gómez Vázquez, D., & Garcia-Sanz, S. (2025). Cognitive control and metacognitive awareness: Do they shape academic achievement in university students? *Frontiers in Psychology*, 16, Article 1633996. <https://doi.org/10.3389/fpsyg.2025.1633996>
- National Research Council. (2001). *Adding it up: Helping children learn mathematics*. National Academies Press. <https://doi.org/10.17226/9822>
- Ncube, M., & Luneta, K. (2025). Concept-based instruction: Improving learner performance in mathematics through conceptual understanding. *Pythagoras*, 46(1), Article a815. <https://doi.org/10.4102/pythagoras.v46i1.815>
- Noviyana, H., Rahmawati, F., Kirana, A. R., & Tanod, M. J. (2025). Enhancing elementary students' mathematical problem-solving skills through AI-assisted problem-based learning. *Journal of Integrated Elementary Education*, 5(2), 254–268. <https://doi.org/10.21580/jieed.v5i2.27576>
- Olid-Luque, M., Ayllón-Salas, P., Arco-Tirado, J. L., & Fernández-Martín, F. D. (2025). Impact of self-regulated learning programs in primary education: A systematic review. *Psychology in the Schools*, 62(3), 734–755. <https://doi.org/10.1002/pits.23352>
- Öztürk-Tavşan, N., & İşler-Baykal, I. (2025). Development of prospective elementary teachers' knowledge to teach early algebra through case discussions. *Journal of Mathematics Teacher Education*, 28, 1341–1372. <https://doi.org/10.1007/s10857-024-09642-6>

- Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. *Frontiers in Psychology*, 8, Article 422. <https://doi.org/10.3389/fpsyg.2017.00422>
- Pijera-Díaz, H. J., van de Pol, J., Channa, F., & de Bruin, A. (2023). Scaffolding self-regulated learning from causal-relations texts: Diagramming and self-assessment to improve metacomprehension accuracy? *Metacognition and Learning*, 18, 631–658. <https://doi.org/10.1007/s11409-023-09343-0>
- Rivas, S. F., Saiz, C., & Ossa, C. (2022). Metacognitive strategies and development of critical thinking in higher education. *Frontiers in Psychology*, 13, Article 913219. <https://doi.org/10.3389/fpsyg.2022.913219>
- Sapkota, B., & Hayes, A. H. (2024). Preservice teachers' mathematical knowledge for teaching: Focus on lesson planning and reflection. *School Science and Mathematics*, 124(5), 323–339. <https://doi.org/10.1111/ssm.12644>
- Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology*, 19(4), 460–475. <https://doi.org/10.1006/ceps.1994.1033>
- Schuster, C., Stebner, F., Leutner, D., & Wirth, J. (2020). Transfer of metacognitive skills in self-regulated learning: An experimental training study. *Metacognition and Learning*, 15, 455–477. <https://doi.org/10.1007/s11409-020-09237-5>
- Sercenia, J. C., & Prudente, M. S. (2023). Effectiveness of the metacognitive-based pedagogical intervention on mathematics achievement: A meta-analysis. *International Journal of Instruction*, 16(4), 561–578. <https://doi.org/10.29333/iji.2023.16432a>
- Smit, R., Hess, K., Taras, A., Bachmann, P., & Dober, H. (2023). The role of interactive dialogue in students' learning of mathematical reasoning: A quantitative multi-method analysis of feedback episodes. *Learning and Instruction*, 86, Article 101777. <https://doi.org/10.1016/j.learninstruc.2023.101777>
- Söderström, S., & Palm, T. (2026). Feedback in mathematics education research: A systematic literature review. *Research in Mathematics Education*, 28(1), 163–184. <https://doi.org/10.1080/14794802.2024.2401488>
- Tak, C. C., Zulnaidi, H., & Eu, L. K. (2025). Mediating role of metacognitive awareness between attitude and mathematics reasoning in pre-service teachers. *European Journal of Science and Mathematics Education*, 13(2), 90–102. <https://doi.org/10.30935/scimath/16116>
- Twohill, A., NicMhuirí, S., Harbison, L., & Karakolidis, A. (2023). Primary preservice teachers' mathematics teaching efficacy beliefs: The role played by mathematics attainment, educational level, preparedness to teach, and gender. *International Journal of Science and Mathematics Education*, 21, 601–622. <https://doi.org/10.1007/s10763-022-10259-5>

- Vergnaud, G. (1997). The nature of mathematical concepts. In T. Nunes & P. Bryant (Eds.), *Learning and teaching mathematics: An international perspective* (pp. 5–28). Psychology Press.
- Vo, K., Sarkar, M., White, P. J., & Yuriev, E. (2024). Development of problem-solving skills supported by metacognitive scaffolding: Insights from students' written work. *Chemistry Education Research and Practice*, 25(4), 1197–1209. <https://doi.org/10.1039/D3RP00284E>
- Vosniadou, S., Darmawan, I., Lawson, M. J., Van Deur, P., Jeffries, D., & Wyra, M. (2021). Beliefs about the self-regulation of learning predict cognitive and metacognitive strategies and academic performance in pre-service teachers. *Metacognition and Learning*, 16, 523–554. <https://doi.org/10.1007/s11409-020-09258-0>
- Wahyuningtyas, L., & Amir, M. F. (2025). Can metaphorical thinking learning model enhance students' mathematical literacy in area conservation? *Journal of Integrated Elementary Education*, 5(1), 128–149. <https://doi.org/10.21580/jieed.v5i1.25690>
- Wang, X.-M., Huang, X.-T., & Zhou, W.-Q. (2024). The effect of university students' self-efficacy on problem-solving disposition: The chained dual mediating role of metacognition disposition and critical thinking disposition. *Thinking Skills and Creativity*, 54, Article 101658. <https://doi.org/10.1016/j.tsc.2024.101658>
- Xie, Y., Zeng, F., & Yang, Y. (2024). A meta-analysis of the relationship between metacognition and academic achievement in mathematics: From preschool to university. *Acta Psychologica*, 249, Article 104486. <https://doi.org/10.1016/j.actpsy.2024.104486>
- Xu, X., Broadbent, J., & Zhang, Q. (2024). Cultivating mathematical mindset via online video interventions: A mixed-methods investigation in Chinese higher education. *Frontiers in Psychology*, 15, Article 1494702. <https://doi.org/10.3389/fpsyg.2024.1494702>
- Yu, M., Cui, J., Wang, L., Gao, X., Cui, Z., & Zhou, X. (2022). Spatial processing rather than logical reasoning was found to be critical for mathematical problem-solving. *Learning and Individual Differences*, 100, Article 102230. <https://doi.org/10.1016/j.lindif.2022.102230>
- Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory Into Practice*, 41(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2