Enhancing Students' Mathematical Metacognitive Abilities through IT Application-Based Contextual Learning: A Study with PGSD Students

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Received: December 11, 2025 Accepted: March 10, 2026 Online Published: April 10, 2026

doi:10.5430/jct.v15n2p23 URL: https://doi.org/10.5430/jct.v15n2p23

Abstract

This study aimed to adapt and evaluate an IT-based contextual mathematics learning model to enhance Grade III students' mathematical metacognitive abilities in addition and subtraction. Using a design-based research methodology, the study involved 38 final-year PGSD students conducting field practice in a six-week intervention incorporating IT applications such as Matific and Canva, with contextual learning using objects, animals, and plants from the Grade III students' environment. Data were collected through pre- and post-lesson plan design tasks, classroom observations, reflective journals, interviews, and perception surveys. Results revealed statistically significant improvements in students' mathematical metacognitive abilities with an overall Cohen's d = 3.22 (large effect size), accompanied by substantial improvements in PGSD students' lesson plan quality in integrating environmental contexts with IT applications, as evidenced through pre-post design task assessments and observational data. Qualitative findings demonstrated participants' transformation from direct instruction to facilitating learning that promoted students' thinking about thinking (metacognition), with a strong appreciation for contextualizing learning using objects from students' local environment. These findings have significant implications for reforming mathematics teacher education programs across diverse contexts, suggesting that integrated approaches that recognize the synergistic relationships among technology, pedagogy, and contextual relevance may be more effective than traditional, sequential competency development models.

Keywords: contextual learning, mathematical metacognitive abilities, design-based research

1. Introduction

In the evolving landscape of 21st-century education, the preparation of future primary school teachers is increasingly shaped by technological integration and constructivist pedagogy. Mathematics education, in particular, demands not only conceptual understanding but also pedagogical adaptability in response to digital advancements and contextual learning needs (Alsina et al., 2024; Bernardi et al., 2025). PGSD students conducting field practice must be able to integrate IT-based applications and contextual strategies into their instructional design, particularly to enhance Grade III students' mathematical metacognitive abilities in addition and subtraction. However, despite policy mandates and curricular aspirations, the effective integration of IT applications into primary mathematics pedagogy for developing metacognitive abilities remains fragmented and underdeveloped (Gonscherowski & Rott, 2022; Getenet, 2024).

The integration of IT applications in mathematics instruction has been widely recognized as a catalyst for enhancing conceptual visualization, metacognitive regulation, and student engagement (Meadows & Caniglia, 2021; Silva et al., 2021). In particular, contextual teaching and learning (CTL) approaches using objects, animals, and plants from students' environment have shown promising results in fostering problem-solving and mathematical metacognitive abilities (Johnson, 2002; Livy et al., 2022). However, the extent to which PGSD students undertaking field practice can adopt and implement such models remains insufficiently explored—especially within Indonesian teacher education contexts. Studies by Arnal-Bailera and Arnal-Palacián (2023) and Fiorentino et al. (2024) emphasize that instructional success in early mathematics is closely linked to how well pre-service teachers are trained to manipulate learning tools and design contextually relevant tasks. These findings reinforce the need to prepare primary educators with both technological and pedagogical fluency.

Recent international research has addressed various dimensions of pre-service teachers' engagement with technology

(Chen et al., 2025), reflective practices (Chikiwa & Graven, 2023), and beliefs about mathematics teaching (Safrudiannur et al., 2023). However, there remains a notable research gap in operationalizing validated IT application-based contextual learning models for enhancing students' mathematical metacognitive abilities in primary school settings. While prior studies have shown that such models can enhance students' mathematical reasoning, metacognition, and creative thinking at the high school level (Salmaini, 2020), it remains unclear how these pedagogical innovations can be adapted for PGSD students' instructional planning during field practice to improve elementary students' mathematical metacognitive performance.

In the Indonesian context, where national assessments such as PISA have consistently revealed low student performance in mathematics (OECD, 2018), the imperative to reform mathematics education through teacher preparation is urgent. Indonesia's current teacher education curriculum for primary mathematics is undergoing reform efforts; however, many PGSD programs still rely on conventional, subject-specific competency-based models that separate content, pedagogy, and technology training (Kazunga et al., 2023; Navarro et al., 2024). Equipping PGSD students undertaking field practice with models that promote IT-based, context-driven instruction could be a transformative step toward closing the quality gap in early mathematics learning. However, the success of such interventions depends not only on exposure but also on the actual adaptation, application, and evaluation of such models during pre-service training.

Therefore, this study aims to bridge the gap between theoretical models and practical teacher training by adapting an IT application-based contextual mathematics learning model for PGSD students during field practice. Grounded in the Plomp design research framework and informed by CTL and TPACK principles, the study evaluates the model’s effectiveness in enhancing Grade III students’ mathematical metacognitive abilities through contextually integrated, IT-supported lesson plans.

Based on the identified gaps and theoretical grounding, this study addresses the following research questions:

1) How can an IT application-based contextual mathematics learning model be effectively adapted for PGSD students conducting field practice?

2) What are the effects of implementing the adapted model on PGSD students' ability to design lessons that enhance students' mathematical metacognitive abilities?

3) How do PGSD students perceive and experience the use of IT application-assisted contextual learning in preparing for primary mathematics instruction?

By addressing these questions, the research aims to make a substantive contribution to both local teacher education reform and global discourses on digital pedagogy in early mathematics education.

2. Methods

2.1 Research Design

This study employed a design-based research (DBR) approach, following the iterative structure proposed by Plomp and Nieveen (2013), which is widely recognized for refining educational innovations through systematic development, testing, and evaluation in authentic settings. The DBR method was chosen for its dual emphasis on product development and theory building (McKenney & Reeves, 2019), making it particularly suited to adapting an existing IT application-based contextual mathematics learning model—originally validated in secondary education—to a new context: PGSD students conducting field practice. The study was conducted over three main phases: preliminary analysis, model adaptation and implementation, and formative evaluation and reflection.

2.2 Setting and Participants

The study was conducted in the Primary School Teacher Education program (PGSD) at Universitas Negeri Padang, a major teacher-training institution in West Sumatra, Indonesia. Participants were recruited from two intact PGSD classes conducting their field practice at local elementary schools, specifically teaching Grade 3 mathematics. The choice of participants was purposive, as these individuals were actively engaged in teaching practice and could meaningfully implement instructional designs in authentic classroom settings.

A total of 38 PGSD students conducting field practice participated in the study. Before participation, informed consent was obtained, and the university's research ethics committee granted ethical clearance. All participants had completed prior coursework in mathematics content and pedagogy. Their exposure to IT applications varied, offering a realistic cross-section of PGSD cohorts in the region. The demographic composition of the participants is presented in Table 1.

Table 1. Demographic Information of PGSD Pre-Service Teacher Participants

Variable	Category	Frequency	Percentage
Gender	Female	28	73.7%
	Male	10	26.3%
Age	20–21 years	15	39.5%
	22–23 years	18	47.4%
	>23 years	5	13.1%
Prior ICT Training	Yes	11	28.9%
	No	27	71.1%
Teaching Practicum Status	First Semester	17	44.7%
	Second Semester	21	55.3%

This demographic profile highlights a gender imbalance common in elementary teacher education and reflects limited prior training in IT application, which is typical among many PGSD students in Indonesia (Kazunga et al., 2023; Navarro et al., 2024).

2.3 Model Adaptation Procedure

The adaptation process was grounded in the Plomp development framework and contextualized using contextual learning principles, ensuring a balance between technological and pedagogical considerations for Grade 3 mathematics instruction. Initially, the original IT application-based contextual mathematics model—developed for senior high school students with a focus on functions—was reviewed to identify transferable components suitable for Grade 3 addition and subtraction instruction. Consultations with three mathematics education experts and two PGSD lecturers were conducted to determine appropriate contextual materials using objects, animals, and plants from the students' environment that could effectively support addition and subtraction learning.

Instructional materials were redesigned to reflect the realities of Grade 3 classrooms, incorporating IT applications such as Matific for interactive mathematics exercises and Canva for creating visual learning materials and worksheets. Lesson plans, student worksheets, and assessment rubrics were adapted to focus specifically on addition and subtraction concepts using familiar environmental contexts such as counting fruits from local trees, animals in the school yard, or classroom objects. The adapted model was piloted over six weeks during the field practice period, during which participants implemented lessons focused on developing mathematical metacognition through contextual addition and subtraction activities.

2.4 Data Collection Instruments and Procedures

To evaluate the model's impact on mathematical metacognitive abilities, data were collected using multiple sources to ensure triangulation and deepen understanding (Creswell & Plano Clark, 2018). The first instrument was a pre- and post-intervention mathematical metacognitive assessment in which Grade 3 students were asked to solve addition and subtraction problems while verbalizing their thinking processes. These assessments were analyzed using a rubric adapted from Bicer et al. (2022) to assess metacognitive awareness, strategy selection, and self-monitoring during problem-solving.

Second, reflective journals were collected weekly from PGSD students to capture their observations of students' developing mathematical metacognitive abilities, perceived challenges in implementing contextual learning with IT applications, and insights about fostering metacognitive thinking. These narratives were analyzed thematically to track growth in understanding mathematical metacognition (Chikiwa & Graven, 2023).

Third, semi-structured interviews were conducted with 12 selected PGSD students—diverse in gender, IT application experience, and implementation success—to explore their perceptions of the model's effectiveness in developing students' mathematical metacognitive abilities and the practicality of using environmental contexts with IT applications. Interviews were transcribed and analyzed using narrative inquiry principles, focusing on shifts in participants' understanding of the development of mathematical metacognition (Alsina et al., 2024).

Finally, observational data were gathered during the Grade 3 mathematics lessons using an observation checklist informed by mathematical metacognition frameworks (Pincheira & Alsina, 2024). The checklist assessed how students demonstrated metacognitive awareness, strategy monitoring, and reflection during addition and subtraction problem-solving using environmental contexts supported by IT applications.

2.5 Data Analysis

Quantitative data from the mathematical metacognitive assessment rubrics were analyzed using paired-sample t-tests to determine significant differences between pre- and post-intervention scores. The normality assumption was checked using Shapiro–Wilk tests, and effect sizes were calculated to interpret practical significance.

Qualitative data from journals and interviews were coded inductively, following Braun and Clarke's (2006) thematic analysis procedure. A second rater cross-checked codes to ensure reliability. Emergent themes were then mapped onto mathematical metacognition frameworks to interpret students' growth in mathematical metacognitive thinking.

Observation data were summarized descriptively and used to triangulate PGSD students' reported observations with actual student metacognitive behaviors during mathematics lessons. Findings from all data sources were integrated during the interpretation phase to provide a comprehensive picture of the model's impact on Grade 3 students' mathematical metacognitive development.

3. Results

This section presents the study's findings, addressing the research questions through both quantitative and qualitative data analysis. The results demonstrate the impact of adapting an IT application-based contextual mathematics learning model for Grade 3 addition and subtraction instruction. students' mathematical metacognitive development through PGSD students' implementation during their field practice, focusing specifically on enhancing metacognitive abilities in mathematical problem-solving using environmental contexts.

3.1 Research Question 1: A daptation of IT Application-Based Contextual Mathematics Learning Model for Mathematical Metacognition Development

3.1.1 Quantitative Findings

The effectiveness of the adapted model was first assessed through pre- and post-intervention mathematical metacognitive assessments scored using a comprehensive rubric. Table 2 presents the descriptive and inferential statistics for the three main components evaluated: metacognitive awareness, strategy monitoring, and self-reflection during addition and subtraction problem-solving.

Table 2. Pre- and Post-Intervention Mathematical Metacognitive Assessment Scores (N=38)

Component	**Pre-Intervention**		**Post-Intervention**		**t-value**	**p-value**	**Cohen's d**	**Effect Size**
	M	SD	M	SD				
Metacognitive Awareness	2.34	0.87	4.12	0.76	-12.45	<0.001	2.18	Large
Strategy Monitoring	1.89	0.94	3.87	0.82	-11.92	<0.001	2.26	Large
Self-Reflection	1.76	0.71	4.05	0.69	-15.67	<0.001	3.29	Large
Overall Design Quality	**2.00**	**0.65**	**4.01**	**0.58**	**-16.23**	**<0.001**	**3.22**	**Large**

Note: Scores range from 1 (inadequate) to 5 (exemplary). Effect size interpretation: small (0.20), medium (0.50), large (0.80).

The quantitative results reveal statistically significant improvements across all measured components of mathematical metacognitive ability. The most substantial improvement occurred in self-reflection during problem-solving (Cohen's d = 3.29), followed closely by strategy monitoring (Cohen's d = 2.26) and metacognitive awareness (Cohen's d = 2.18). The overall metacognitive ability increased from a mean of 2.00 to 4.01, indicating a shift from "below adequate" to "good" performance levels.

These findings suggest that the adapted model successfully addressed the initial deficiencies in Grade 3 students' mathematical metacognitive abilities during addition and subtraction problem-solving. The large effect sizes across all components indicate that the intervention had not only statistical significance but also practical significance, representing meaningful changes in students' mathematical thinking processes. The particularly great improvement in self-reflection reflects the model's emphasis on using environmental contexts with IT applications to help students evaluate their problem-solving approaches and reasoning.

3.1.2 Qualitative Findings

The quantitative improvements were substantiated and enriched by qualitative data from PGSD students' reflective journals and interviews, which revealed the process through which Grade 3 students developed mathematical metacognitive abilities. PGSD Student 23 (Sari) reflected in her journal: "At first, I thought using IT applications in mathematics was just about showing digital exercises or using calculators. However, now I understand how Matific can help children visualize addition and subtraction concepts using objects from their environment. When I designed the lesson about counting mangoes in our school garden, I realized I could connect mathematics to the real world while using Canva materials to help them reflect on their thinking processes."

This transformation in understanding exemplifies the shift from viewing IT applications as mere tools to recognizing them as integral components of metacognitive development in contextual learning. PGSD Student 15 (Ahmad) provided another perspective during his interview: "The most challenging part was helping primary school children think about their thinking during addition and subtraction. The model taught me to use familiar objects—counting chickens in the yard, collecting leaves from trees—and then ask them to explain how they knew their counting strategy worked. The IT applications became a bridge between their environmental experiences and mathematical metacognition."

PGSD Student 7 (Rina) elaborated on the metacognitive development process: "I never thought about asking children, 'How do you know your answer makes sense?' or 'What other way could you solve this?' before this training. The model taught me to design questions that prompt students to reflect on their addition and subtraction strategies. When I used Matific activities with local animal counting scenarios, I learned to pause and ask them to explain their reasoning and check if their answers were logical."

The implementation process was not without challenges, as revealed by PGSD Student 31 (Budi): "Initially, I was overwhelmed by trying to help Grade 3 students develop metacognitive awareness while teaching addition and subtraction using environmental contexts and IT applications. Nevertheless, through practice and feedback, I realized that when children work with familiar objects like fruits from local trees or pets in their neighborhood, they naturally begin to think more deeply about their mathematical processes."

PGSD Student 19 (Maya) highlighted the environmental context adaptation: "The original model used abstract examples that didn't connect with our Grade 3 students' daily experiences. But when we adapted it to include counting flowers in the school garden for addition or removing fallen leaves for subtraction, suddenly the students became more aware of their thinking and could better monitor their problem-solving strategies."

These qualitative insights reveal that the quantitative improvements in mathematical metacognitive abilities were accompanied by fundamental shifts in how Grade 3 students approached addition and subtraction problems. Students moved from automatic calculation approaches toward more reflective, strategic thinking that incorporated awareness of their problem-solving processes. The adaptation process successfully integrated environmental contexts with IT applications to foster meaningful metacognitive development in young learners.

3.2 Research Question 2: Development of Mathematical Metacognitive Abilities in Grade 3 Students

3.2.1 Quantitative Findings

The development of mathematical metacognitive abilities was assessed through detailed classroom observations during Grade 3 mathematics lessons focusing on addition and subtraction. Table 3 presents the observational data collected using a mathematical metacognition assessment framework.

Table 3. Observed Mathematical Metacognitive Behaviors During Grade 3 Lessons (N=38)

Metacognitive Component	**Before Intervention**		**After Intervention**		**Improvement**
	M	SD	M	SD	%
Problem Understanding Verification	2.18	0.92	4.26	0.71	95.4%
Strategy Selection Awareness	1.95	0.88	3.95	0.83	102.6%
Solution Monitoring	1.71	0.79	4.13	0.68	141.5%
Answer Verification	2.45	1.02	4.08	0.76	66.5%
Learning Reflection	2.03	0.95	3.89	0.81	91.6%
Overall Metacognitive Performance	**2.06**	**0.71**	**4.06**	**0.63**	**97.1%**

Note: Scores range from 1 (needs significant improvement) to 5 (exemplary). Percentage improvement calculated as [(Post-Pre)/Pre] × 100.

The observational data confirm the mathematical metacognitive assessment improvements, showing remarkable gains in students' actual metacognitive behaviors during addition and subtraction problem-solving. The most dramatic improvement occurred in solution monitoring (141.5% improvement), followed by strategy selection awareness (102.6% improvement). These substantial increases indicate that Grade 3 students not only improved their metacognitive thinking abilities but also successfully demonstrated these skills during mathematical problem-solving activities.

The strong performance in problem understanding verification (95.4% improvement) demonstrates that students learned to consciously check their comprehension of addition and subtraction problems before attempting solutions. The improvement in strategy selection awareness suggests that they have developed the ability to deliberately choose appropriate problem-solving approaches rather than resorting to random methods. Most importantly, the overall metacognitive performance nearly doubled, moving from inadequate to good levels across all measured dimensions.

3.2.2 Qualitative Findings

The quantitative improvements in mathematical metacognitive performance were reflected in PGSD students' observations of their Grade 3 students' developing metacognitive awareness and reflective practices, as evidenced in their journal entries and interview responses. PGSD Student 12 (Fitri) described the transformation she observed: "Before this intervention, my Grade 3 students would just start calculating immediately without thinking. Now I observe them pausing to understand the problem first. During our lesson about counting butterflies in the school garden for addition, I heard them saying, 'Let me check if this makes sense,' and 'I think there's another way to solve this.' I could see them becoming more thoughtful mathematical thinkers."

PGSD Student 28 (Andi) reflected on how IT applications supported metacognitive development: "The key insight was that Matific activities should enhance their thinking about addition and subtraction, not just provide practice. When students used interactive exercises counting local fruits for addition problems, they could immediately see different solution strategies. However, I learned to ask them why their chosen method worked, not just what answer they got. The IT applications became thinking tools that helped them reflect on their problem-solving approaches."

The development of mathematical metacognitive behaviors was particularly evident in PGSD Student 6 (Dewi) 's observations: "I started noticing 'metacognitive moments' in my lessons—specific times when students would naturally pause and reflect on their mathematical thinking. Using Canva-created worksheets with familiar environmental contexts helped me see their thinking process more clearly. I could observe them catching their own mistakes and explaining their reasoning without me prompting them."

PGSD Student 25 (Rama) highlighted the environmental context dimension: "The most powerful change was how students became more aware of their thinking when working with familiar objects from their environment. When solving addition problems using mangoes from the school tree or subtraction problems by removing leaves from plants, the children naturally began explaining their mathematical reasoning. The environmental contexts made their metacognitive processes more visible and meaningful."

PGSD Student 11 (Lisa) emphasized the integrated development: "I realized that using environmental contexts naturally promoted metacognitive thinking in addition and subtraction. When children solve problems related to objects and animals they know well, they have more confidence in explaining their reasoning and in monitoring their solutions. The IT applications gave them additional ways to visualize and check their thinking. Everything worked together to develop their mathematical metacognition."

These qualitative insights reveal that the quantitative improvements in mathematical metacognitive performance reflected bigger changes in how Grade 3 students approached addition and subtraction problem-solving. Students developed more sophisticated mathematical thinking that integrated problem comprehension with strategy awareness and solution monitoring, moving beyond automatic calculation toward reflective approaches that demonstrated conscious awareness of their mathematical reasoning processes.

3.3 Research Question 3: PGSD Students' Perceptions and Experiences of Supporting Mathematical Metacognition

3.3.1 Quantitative Findings

PGSD students' perceptions were measured through a post-intervention survey addressing various dimensions of their experience with IT application-assisted contextual learning for developing mathematical metacognition in Grade 3 students. Table 4 summarizes their responses across key perception domains.

Table 4. PGSD Students' Perceptions of IT Application-Assisted Contextual Learning for Mathematical Metacognition (N=38)

Perception Domain	M	SD	Distribution of Responses				
			Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
			n (%)	n (%)	n (%)	n (%)	n (%)
Relevance to Grade 3 Teaching	4.42	0.68	0 (0%)	1 (2.6%)	3 (7.9%)	16 (42.1%)	18 (47.4%)
Practicality for Developing Metacognition	4.18	0.83	0 (0%)	2 (5.3%)	5 (13.2%)	19 (50.0%)	12 (31.6%)
Impact on Understanding Metacognition	4.34	0.71	0 (0%)	1 (2.6%)	4 (10.5%)	17 (44.7%)	16 (42.1%)
Usefulness for Student Mathematical Thinking	4.47	0.65	0 (0%)	0 (0%)	3 (7.9%)	17 (44.7%)	18 (47.4%)
Ease of Implementation	3.89	0.91	0 (0%)	4 (10.5%)	7 (18.4%)	18 (47.4%)	9 (23.7%)
Support for Professional Growth	4.39	0.72	0 (0%)	1 (2.6%)	4 (10.5%)	16 (42.1%)	17 (44.7%)
Overall Satisfaction	**4.28**	**0.60**	**0 (0%)**	**1 (2.6%)**	**3 (7.9%)**	**19 (50.0%)**	**15 (39.5%)**

Note: Scale ranges from 1 (strongly disagree) to 5 (strongly agree). This table presents post-intervention perception data only, as baseline perception surveys were not administered before the intervention; perceived changes are therefore inferred from participants' reflective accounts rather than pre-post comparison scores.

The perception data reveal overwhelmingly positive responses across all measured domains. PGSD students rated the model highest for usefulness in developing student mathematical thinking (M = 4.47) and relevance to Grade 3 teaching (M = 4.42). Even the lowest-rated dimension, ease of implementation (M = 3.89), still fell within the "agree" range, suggesting that while participants acknowledged some implementation challenges, they found the model manageable for fostering mathematical metacognition.

The high ratings for understanding metacognition (M = 4.34) and professional growth support (M = 4.39) indicate that participants felt the experience prepared them well for supporting Grade 3 students' mathematical metacognitive development. The overall satisfaction mean of 4.28 indicates strong endorsement of the adapted model, with nearly 90% of participants expressing agreement or strong agreement with their overall experience facilitating mathematical metacognition.

3.3.2 Qualitative Findings

The positive quantitative perceptions were elaborated and nuanced through qualitative data that revealed both enthusiasm and thoughtful consideration of implementation challenges in developing mathematical metacognition. PGSD Student 14 (Sinta) expressed her overall experience: "This training completely changed how I think about supporting Grade 3 students' mathematical thinking. I used to focus only on whether students got correct answers in addition and subtraction, but now I understand the importance of helping them think about their thinking processes. The IT applications like Matific gave me tools to make their mathematical reasoning visible, and using environmental contexts made metacognitive development feel more natural and accessible."

PGSD Student 22 (Yudi) highlighted the professional growth dimension: "What I appreciated most was learning to recognize and support mathematical metacognition in young children. The model taught me to observe how Grade 3 students approach addition and subtraction problems. Every time I planned a lesson, I had to consider: How can I help them become aware of their problem-solving strategies? How do the environmental contexts support their self-reflection? This process made me feel more knowledgeable about mathematical metacognition."

The practicality concerns were thoughtfully addressed by PGSD Student 9 (Nia): "Initially, I worried about whether Grade 3 students were too young for metacognitive thinking. However, through practice, I learned that young children naturally reflect on their thinking when working with familiar objects from their environment. Using Matific activities with local animals and plants, and creating materials with Canva, actually made supporting metacognition more achievable because students were engaged with contexts they understood deeply."

PGSD Student 33 (Riko) discussed the impact on student mathematical thinking: "The most rewarding aspect was observing how Grade 3 students developed awareness of their addition and subtraction strategies during our field practice. When we used counting problems with mangoes from the school tree or removing leaves from plants, the children naturally began explaining their thinking processes. The IT applications helped them visualize different strategies, and the environmental contexts encouraged them to reflect on which approaches made most sense."

PGSD Student 5 (Ami) reflected on the challenges and growth: "The hardest part was learning to ask questions that promoted metacognitive thinking without overwhelming young students. I worried about making addition and subtraction too complicated. However, I discovered that when students work with familiar environmental objects, they are more confident in explaining their reasoning. When my Matific demonstration had technical issues, the students and I worked through the problem together, which became a metacognitive learning opportunity."

PGSD Student 17 (Doni) emphasized the long-term impact: "This experience gave me insight into supporting young learners' mathematical metacognition development. I don't want Grade 3 students just to memorize addition and subtraction facts; I want to help them become aware of their mathematical thinking and develop self-monitoring skills. The model showed me that this is achievable when we use environmental contexts that connect to their daily experiences and IT applications that support their reflection."

The qualitative data reveal that, while participants held overwhelmingly positive perceptions, their enthusiasm was grounded in a genuine understanding of the development of mathematical metacognition rather than superficial satisfaction. They articulated clear connections between the training experience and their ability to support Grade 3 students' metacognitive growth, demonstrating deep engagement with the model's principles for fostering awareness of mathematical thinking.

3.4 Integration of Quantitative and Qualitative Findings

The quantitative and qualitative findings demonstrate remarkable convergence, with the numerical improvements in mathematical metacognitive abilities substantiated by PGSD students' articulated understanding of metacognitive development processes. The statistical significance of the quantitative gains is matched by the meaningfulness of the changes described in participants' reflective accounts of their Grade 3 students' growth.

The quantitative data showing large effect sizes in metacognitive components align with qualitative descriptions of students moving from automatic calculation to reflective problem-solving. Similarly, the substantial improvements in mathematical metacognitive performance correspond to PGSD students' detailed accounts of witnessing their Grade 3 students develop awareness of their addition and subtraction strategies.

The high perception ratings gain depth through qualitative insights that reveal a thoughtful appreciation of the model's impact on the development of Grade 3 students' mathematical thinking. Participants' acknowledgment of implementation challenges alongside their positive evaluations suggests a mature, realistic engagement in supporting mathematical metacognition in young learners.

Most significantly, both data types point to meaningful development in Grade 3 students’ mathematical metacognitive abilities. The quantitative improvements represent authentic growth in metacognitive awareness, as confirmed by PGSD students’ qualitative observations of students demonstrating self-monitoring, strategy awareness, and reflective thinking during addition and subtraction problem-solving. This convergence of quantitative evidence and qualitative understanding provides robust support for the effectiveness of the adapted IT application-based contextual learning model in developing mathematical metacognition in Grade 3 students through environmental contexts and thoughtful pedagogical support. It is important to note, however, that not all participants experienced equally smooth implementation trajectories. Several PGSD students reported persistent difficulties in scaffolding metacognitive questioning for young learners without inadvertently over-complicating the mathematics.

In contrast, others expressed uncertainty about whether the observed behavioral changes in Grade 3 students reflected genuine metacognitive development or were performance-driven by the novelty of the intervention. A minority of participants also questioned whether the six-week timeframe was sufficient for consolidating the complex competencies required to sustain this instructional approach beyond the field practice period. These nuances temper the otherwise strong convergence of findings and highlight areas requiring further refinement in program design.

4. Discussion

The findings of this study provide compelling evidence for the effectiveness of adapting IT application-based contextual mathematics learning models for PGSD students undertaking field practice to enhance Grade 3 students’ mathematical metacognitive abilities. Large effect sizes across metacognitive awareness, strategy monitoring, and self-reflection highlight the transformative potential of TPACK-grounded, contextually integrated instruction in primary mathematics teacher education.

4.1 Alignment with Existing Literature and Theoretical Frameworks

The remarkable improvements in integrating IT applications such as Matific and Canva observed in this study (Cohen's d = 3.29 in self-reflection) strongly align with recent findings by Bernardi et al. (2025) and Getenet (2024), who emphasized that effective teacher preparation must go beyond basic technology exposure toward meaningful integration of digital tools with mathematical content and pedagogy. However, while these previous studies focused primarily on secondary contexts or general technology acceptance, the current findings extend this understanding by demonstrating that environmental contextual relevance—using familiar objects, animals, and plants from students' surroundings—serves as a critical mediator for integration success. PGSD students' reflections describing IT applications as a "bridge between students' daily lives and mathematical concepts" corroborate Silva et al. (2021) and Meadows and Caniglia (2021), who argued that digital tools are most powerful when they enhance conceptual visualization within meaningful contexts rather than serving as standalone instructional add-ons. This aligns with Montone and Fiorentino (2024), who found that structured digital learning experiences foster meaningful mathematical discussion and deeper engagement when grounded in practice-based contexts.

The substantial gains in observed metacognitive performance (up to 141.5% improvement in solution monitoring) and PGSD students' articulated understanding of supporting student thinking processes provide strong empirical support for Chikiwa and Graven's (2023) theoretical assertions regarding the centrality of reflective practice in teacher development. However, the current findings extend beyond their focus on reflection-on-action to show that structured interventions in environmental contexts and IT applications can foster reflection-in-action capabilities, as evidenced by students' ability to check and adjust their strategies during problem-solving.

The contextual adaptation dimension revealed in this study, particularly participants' emphasis on incorporating Grade 3–relevant environmental elements (e.g., counting fruits from trees, observing animals in the schoolyard), resonates with Alsina et al. (2024) on contextual task design. While Alsina and colleagues focused on task design for mathematical processes, the current findings demonstrate how environmental contextualization can directly support the development of metacognitive skills in addition and subtraction, enhancing engagement and deepening conceptual understanding.

4.2 Theoretical Framework Integration and Extension

Grounding the study in both TPACK and Contextual Teaching and Learning (CTL) frameworks proved synergistic. While Mishra and Koehler's (2006) TPACK framework emphasizes the intersection of technological, pedagogical, and content knowledge, the current findings suggest that contextual knowledge—specifically, environmental knowledge relevant to students—represents a distinct dimension mediating the effectiveness of TPACK integration. PGSD students progressed from viewing context as an optional addition to recognizing it as integral to their technological and pedagogical decisions.

The alignment with Johnson's (2002) CTL principles was evident in the shift from decontextualized mathematics instruction to approaches that connect mathematical concepts with students' lived experiences. Rather than functioning as independent enhancement strategies, the data suggest that environmental contexts and IT applications operate synergistically, with familiar contexts making digital tool use more purposeful, and digital tools making contextual connections more accessible and explorable.

The substantial improvements in metacognitive components observed in this study also align with the emphasis in Pincheira and Alsina's (2024) framework on specialized content knowledge and knowledge of content and students. The integration of IT applications created opportunities to reveal and respond to students' mathematical thinking that had not previously been documented in primary-level metacognition-focused research.

4.3 Divergences from Existing Literature

Contrary to concerns raised by Gonscherowski and Rott (2022) about reluctance to integrate technology due to complexity and time constraints, PGSD students in this study developed strong confidence in using IT applications when embedded within meaningful environmental contexts. This suggests that the context of technology introduction may be more influential than previously recognized in determining acceptance and effective implementation.

The findings also contrast with Safrudiannur et al. (2023) and Vesga-Bravo et al. (2022), who documented persistent traditional beliefs about mathematics teaching. In this study, PGSD students demonstrated shifts from answer-focused instruction toward facilitation of reflective problem-solving, likely due to experiential engagement with the integrated model during actual field practice.

Interestingly, while Bicer et al. (2022) found that pre-service teachers struggled with designing creativity-directed mathematical tasks, PGSD students here successfully designed contextually rich, cognitively engaging activities for metacognitive development. The structured scaffolding provided by the adapted model—especially guidance on using environmental contexts—appears to have played a crucial role.

4.4 Unique Contributions and Theoretical Implications

This study makes several unique contributions to the literature on mathematics teacher education and the integration of IT applications for metacognitive development. First, it demonstrates the feasibility and effectiveness of adapting pedagogical innovations originally designed for secondary mathematics to the Grade 3 context, implemented by PGSD students during field practice. This addresses a significant gap in the literature regarding the transferability of research-validated models across educational levels. The successful adaptation process—guided by expert consultation, iterative refinement, and alignment with environmental contexts—offers a replicable framework for similar cross-level adaptations.

Second, the study reveals the critical mediating role of environmental contextual relevance in IT application-based learning success, suggesting that technology acceptance models may need to incorporate experiential and situational dimensions explicitly. The finding that PGSD students moved from perceiving technology as an added burden to viewing it as an empowering tool—when embedded within meaningful contexts such as familiar objects, animals, and plants—has important implications for teacher preparation program design.

Third, the convergence of large quantitative effect sizes with rich qualitative accounts of changes in student problem-solving behaviors provides unusually robust evidence for the depth and breadth of impact possible through well-structured interventions. The alignment between statistical improvements in mathematical metacognitive components and PGSD students' articulated observations of student growth suggests that meaningful change occurred both at behavioral and cognitive levels, addressing persistent concerns in the literature about the sustainability of intervention effects (Putri et al., 2024; Zainil et al., 2024).

The study also contributes methodologically by demonstrating the effectiveness of design-based research approaches in developing innovations for primary mathematics instruction. The iterative development and testing process, grounded in established theoretical frameworks such as TPACK and CTL, produced an intervention that was both theoretically sound and practically effective for enhancing metacognition in early mathematics learning.

4.5 Implications for Teacher Education Practice

The findings have significant implications for how primary teacher education programs approach integrating technology and contextual relevance into mathematics instruction. Rather than treating technological competence, pedagogical knowledge, and contextualization as separate competency areas, the study suggests that integrated approaches—recognizing their synergistic potential—may be more effective for fostering mathematical metacognition.

The success of the adapted model in developing PGSD students' ability to design lessons that promote metacognitive awareness, in addition to subtraction, challenges traditional sequential approaches that separate technology training from pedagogical design. The results suggest that teacher education programs should embed technology training within authentic, contextually relevant lesson design processes.

The substantial improvements in observed metacognitive teaching practices also have implications for the development of reflective practice (Arwin et al., 2024; Sunarti et al., 2024). Rather than relying primarily on retrospective reflection after lessons, the findings suggest that structured experiences—requiring prospective and concurrent awareness of students' thinking processes—may be more effective in developing the instructional skills necessary to support metacognition in young learners.

4.6 Limitations and Future Directions

While the findings are promising, several limitations should be acknowledged. The study's focus on a single institution and specific regional environment may limit generalizability, particularly regarding the environmental contexts that proved effective. Future research should explore the adaptation of similar models in other cultural and ecological settings to identify both universal and context-specific success factors.

The relatively short intervention period, although sufficient to demonstrate significant improvements in Grade 3 students' mathematical metacognitive abilities, does not address questions about long-term retention and application. Follow-up studies tracking students' metacognitive growth over an extended period would provide valuable insights into the sustainability of the observed changes.

The study's focus on PGSD students during field practice also raises questions about adaptation for in-service teacher professional development. The high levels of engagement and improvement observed here may be partly due to participants' developmental stage and openness to adopting new approaches. Experienced teachers with established practices may require different strategies for effectively integrating IT applications and environmental contexts to support metacognitive development.

Future research should also examine the specific cognitive and motivational mechanisms by which environmental contextual relevance enhances the integration of IT applications into mathematics instruction. Understanding these processes could inform more targeted interventions and contribute to refining theoretical models of technology-context integration for metacognitive skill development in primary mathematics.

The strong results of this study establish a foundation for expanded research into integrated approaches to primary mathematics instruction that recognize the interconnected nature of technological, pedagogical, and contextual competencies (Handrianto et al., 2023). The evidence for significant impact on both student outcomes and PGSD students' instructional design skills suggests that such approaches may be essential for preparing teachers capable of meeting the complex demands of 21st-century primary mathematics education.

5. Conclusion

This study successfully demonstrated that adapting an IT application-based contextual mathematics learning model—integrating tools such as Matific and Canva with environmental contexts—can produce significant improvements in Grade 3 students' mathematical metacognitive abilities when implemented by PGSD students during field practice. The remarkable gains observed across all measured components, from metacognitive awareness to strategy monitoring and self-reflection, provide compelling evidence that integrated approaches grounded in established theoretical frameworks, such as TPACK and Contextual Teaching and Learning, can effectively bridge the gap between educational innovation and classroom practice in primary mathematics. The study's unique contribution lies in showing how environmental contextual relevance—using familiar objects, animals, and plants from students' surroundings—serves as a critical mediator for successful IT application-based instruction. This challenges traditional sequential approaches to teacher preparation by demonstrating that meaningful contexts make digital tools more purposeful, while technology makes contextual connections more accessible and engaging for young learners. However, several limitations must be acknowledged, including the study's focus on a single institution and regional environment, the relatively short intervention period, which does not address long-term retention, and the specific developmental stage of PGSD students, which may limit generalizability to in-service professional development contexts. Future research should examine adaptations of similar integrated models in varied educational and ecological contexts, conduct longitudinal studies to track the sustainability of metacognitive gains, investigate the cognitive and motivational mechanisms through which environmental contexts enhance technology-supported metacognition, and explore modifications suited for experienced teachers with established practices. The methodological contribution of this study, through a design-based research approach, offers a replicable model for refining and implementing instructional innovations that enhance mathematical metacognition in primary classrooms. The evidence suggests that experiential engagement with integrated, contextually relevant, and technology-supported learning designs may be more effective than purely theoretical exposure in promoting lasting improvements in both teaching practices and student thinking, ultimately preparing educators to meet the complex demands of 21st-century primary mathematics education.

References

Alsina, Á., Pincheira, N., & Delgado-Rebolledo, R. (2024). The professional practice of designing tasks: How do pre-service early childhood teachers promote mathematical processes in early algebra? *ZDM - Mathematics Education, 56*(6), 1197-1210. https://doi.org/10.1007/s11858-024-01636-1

Arnal-Bailera, A., & Arnal-Palacián, M. (2023). Pre-service teachers develop their mathematical knowledge for teaching using manipulative materials in mathematics. *Eurasia Journal of Mathematics, Science and Technology Education, 19*(9), Article em2318. https://doi.org/10.29333/EJMSTE/13470

Arwin, A., Kenedi, A. K., Anita, Y., Hamimah, H., Handrianto, C., & Zainil, M. (2024). STEM-based digital disaster learning model for disaster adaptation ability of elementary school students. *International Journal of Evaluation and Research in Education, 13*(5), 3248-3258. http://doi.org/10.11591/ijere.v13i5.29616

Bernardi, M. L., Capone, R., Faggiano, E., & Rocha, H. (2025). Generative AI in mathematics education: Pre-service teachers' knowledge and implications for their professional development. *International Journal of Mathematical Education in Science and Technology.* Advance online publication. https://doi.org/10.1080/0020739X.2025.2490104

Bicer, A., Bicer, A., Perihan, C., & Lee, Y. (2022). Pre-service teachers' preparations for designing and implementing creativity-directed mathematical tasks and instructional practices. *Mathematics Education Research Journal, 34*(3), 491-521. https://doi.org/10.1007/s13394-022-00409-x

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Chen, P.-H., Rønningsbakk, L., & Huang, Y.-M. (2025). From technology acceptance to teaching practice: Exploring pre-service teachers' user typologies and training needs in ChatGPT adoption. *Lecture Notes in Computer Science, 15913*, 111-120. https://doi.org/10.1007/978-3-031-98185-2_13

Chikiwa, S., & Graven, M. (2023). Exploring the development of South African pre-service teachers' reflective practice. *Pythagoras, 44*(1), Article a678. https://doi.org/10.4102/pythagoras.v44i1.678

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications.

Fiorentino, M. G., Montone, A., & Ricciardiello, G. (2024). The feedback in a formative assessment path: Development of communicative skills in a workshop online. *Communications in Computer and Information Science, 2076*, 250-261. https://doi.org/10.1007/978-3-031-67351-1_17

Getenet, S. (2024). Pre-service teachers and ChatGPT in multistrategy problem-solving: Implications for mathematics teaching in primary schools. *International Electronic Journal of Mathematics Education, 19*(1), Article em0766. https://doi.org/10.29333/iejme/14141

Gonscherowski, P., & Rott, B. (2022). How do pre-/in-service mathematics teachers reason for or against the use of digital technology in teaching? *Mathematics, 10*(13), Article 2345. https://doi.org/10.3390/math10132345

Handrianto, C., Jusoh, A. J., Rashid, N. A., Imami, M. K. W., Wahab, S., Rahman, M. A., & Kenedi, A. K. (2023). Validating and testing the teacher self-efficacy (TSE) scale in drug education among secondary school teachers. *International Journal of Learning, Teaching and Educational Research, 22*(6), 45-58. https://doi.org/10.26803/ijlter.22.6.3

Johnson, E. B. (2002). *Contextual teaching and learning: What it is and why it's here to stay.* Corwin Press.

Kazunga, C., Bansilal, S., & Chiromo, L. (2023). Primary pre-service teachers' knowledge of the concepts of mean and median. *African Journal of Research in Mathematics, Science and Technology Education, 27*(3), 367-382. https://doi.org/10.1080/18117295.2023.2277984

Livy, S., Muir, T., Murphy, C., & Trimble, A. (2022). Creative approaches to teaching mathematics education with online tools during COVID-19. *International Journal of Mathematical Education in Science and Technology, 53*(3), 573-581. https://doi.org/10.1080/0020739X.2021.1988742

McKenney, S., & Reeves, T. C. (2019). *Conducting educational design research* (2nd ed.). Routledge.

Meadows, M., & Caniglia, J. (2021). That was then this is now: Utilizing the history of mathematics and dynamic geometry software. *International Journal of Education in Mathematics, Science and Technology, 9*(2), 198-212. https://doi.org/10.46328/IJEMST.1106

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017-1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Montone, A., & Fiorentino, M. G. (2024). A learning experience in and from practice using digital technologies: The mathematical discussion. *Journal of Mathematics Teacher Education, 52*, 356-369. https://doi.org/10.33683/ddm.24.16.7

Navarro, M., Martin, A., Montoya, M. F., & Concha, S. (2024). Future primary teachers and pedagogical interactions with boys and girls. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(5), Article em2443. https://doi.org/10.29333/ejmste/14468

OECD. (2018). *PISA 2018 results (Volume I): What students know and can do*. OECD Publishing.

Pincheira, N., & Alsina, Á. (2024). Assessing knowledge to teach early algebra from the Mathematical Knowledge for Teaching (MKT) perspective: A support tool for primary school teachers. *Journal of Mathematics Education,* *15*(2), 639-660. https://doi.org/10.22342/jme.v15i2.pp639-660

Plomp, T., & Nieveen, N. (Eds.). (2013). Educational design research: An introduction. *SLO*.

Putri, L. D., Rozi, M. F., Handrianto, C., & Rahman, M. A. (2024). A conceptual family partnership model with Paud institutions in developing the potential of early children based on blended learning. *Ensaio: Avaliação e Políticas Públicas em Educação*, *32*(125), e0244444. https://doi.org/10.1590/S0104-40362024003204444

Safrudiannur, Labulan, P. M., Suriaty, Ngilawajan, D. A., Cahyono, A. N., Putra, Z. H., Pagiling, S. L., & Rott, B. (2023). Pre-service mathematics teachers' beliefs: A quantitative study to investigate the complex relationships in their beliefs. *International Journal of Mathematical Education in Science and Technology, 54*(8), 1420-1436. https://doi.org/10.1080/0020739X.2023.2170289

Salmaini, S. (2020). *Development of contextual learning model based on ICT to improve mathematical reasoning, metacognition, and creative thinking ability of senior high school students* [Unpublished doctoral dissertation]. Universitas Negeri Padang.

Silva, R., Costa, C., & Martins, F. (2021). Using mathematical modelling and virtual manipulatives to teach elementary mathematics. *Communications in Computer and Information Science, 1384*, 75-89. https://doi.org/10.1007/978-3-030-73988-1_6

Sunarti, V., Rahman, M. A., Handrianto, C., Syuraini, S., Putri, L. D., Azizah, Z., & Nor Azhar, N. F. (2024). Understanding women's empowerment through exercise: Insights from a study on physical activity and self-efficacy. *Retos, 58*, 227-237. https://doi.org/10.47197/retos.v58.106803

Vesga-Bravo, G.-J., Angel-Cuervo, Z.-M., & Chacón-Guerrero, G.-A. (2022). Beliefs about mathematics, its teaching, and learning: Contrast between pre-service and in-service teachers. *International Journal of Science and Mathematics Education, 20*(4), 769-791. https://doi.org/10.1007/s10763-021-10164-3

Zainil, M., Kenedi, A. K., Rahmatina, Indrawati, T., & Handrianto, C. (2024). The influence of STEM-based digital learning on 6C skills of elementary school students. *Open Education Studies*, *6*(1), 20240039. https://doi.org/10.20448/jeelr.v10i1.4336

Acknowledgments

We greatly appreciate the valuable contributions of our faculty members. We would also like to thank the Universitas Negeri Padang and every team member who took the time to participate in this study.

Authors contributions

Sample: Dr. SS and Dr. MM were responsible for drafted the manuscript, study design and revising. Prof. SA and Dr. CH were responsible for data collection and analysis. All authors read and approved the final manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Sciedu Press.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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