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Developing an evaluation instrument for metacognitive-based lessons in mathematics within sustainable and digital learning contexts: Scoping review

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Abstract

This study examined recent trends in metacognitive research in mathematics education and developed an evaluation instrument for evaluating metacognitive-based lessons within digitally mediated and sustainable learning environments. Grounded in the need to strengthen the integration of metacognitive strategies in contemporary classroom instruction, the study addressed gaps in both research synthesis and instructional assessment. A scoping review design guided by PRISMA-ScR protocols was employed to systematically identify, screen, and analyze relevant literature published between 2020 and 2025. Academic databases including ERIC, Scopus, Web of Science, Google Scholar, and Education Source were utilized. From an initial 147 records, 20 studies were selected after duplicate removal and eligibility screening. Data analysis involved descriptive statistics to determine the frequency and distribution of study types (foundational, empirical, and experimental), and thematic analysis to identify instructional practices aligned with the metacognitive processes of planning, monitoring, evaluating, and reflection. The results revealed that empirical studies were most prevalent, followed by experimental and foundational studies, indicating a strong emphasis on classroom-based and practice-oriented applications of metacognitive strategies. Frequently identified approaches included think-aloud protocols, self-regulated learning, cooperative learning, and KWL strategies. Instructional practices consistently embedded metacognitive components through structured lesson objectives, guided digital and collaborative activities, and reflective tasks, reinforcing the roles of teachers as facilitators and learners as active, self-regulated participants in technology-enhanced environments. The findings highlight the need for an evaluation instrument for metacognitive-based lessons that support sustainable and equitable mathematics instruction in digitally transforming educational contexts, contributing to evidence-based pedagogy, curriculum innovation, and the advancement of quality education in line with global goals for sustainable development.

Keywords: Evaluation instrument; Mathematics education; Metacognitive strategies; Scoping review; Sustainable digital learning environments

1. Introduction

This study is grounded in the need to better understand and strengthen the role of metacognition in mathematics education through both research synthesis and instructional evaluation. It examines recent trends in metacognitive research while developing a structured instrument for evaluating metacognitive-based lessons. By integrating these two dimensions, the study provides a comprehensive framework for analyzing existing literature and addressing gaps in the effective and sustainable integration of metacognitive strategies in classroom instruction.

Metacognition plays a central role in contemporary mathematics education as it enhances learners' ability to regulate their thinking through planning, monitoring, evaluating, and reflecting (Schraw, 1998; Zimmerman, 2000). These processes are strongly associated with improved problem-solving skills, conceptual understanding, and independent learning (Panadero, 2017). Learners with developed metacognitive awareness demonstrate greater autonomy, adaptability, and persistence when engaging with complex mathematical tasks. As mathematics education increasingly emphasizes higher-order thinking skills, the integration of metacognitive strategies becomes essential in addressing persistent challenges such as low achievement and mathematics anxiety (OECD, 2022). Thus, metacognition is recognized as a critical component of effective mathematics instruction in the 21st century.

Recent empirical and experimental studies (2020–2025) highlight the effectiveness of instructional approaches such as think-aloud protocols, self-regulated learning [SRL], cooperative learning, and reflective practices in enhancing student engagement and achievement (de Bruin &

van Gog, 2012; Panadero, 2017). These strategies encourage learners to actively monitor and regulate their cognitive processes, thereby strengthening conceptual understanding and problem-solving abilities. However, despite the increasing volume of studies, the literature remains fragmented due to variations in methodologies, instructional designs, and learning contexts. This fragmentation underscores the need for a systematic synthesis of recent research to identify consistent patterns, emerging trends, and gaps in the integration of metacognitive strategies in mathematics education.

The theoretical foundation of this study is anchored in constructivist and cognitive learning theories, which emphasize that learning is an active, reflective, and socially mediated process (Schraw, 1998). Within this framework, metacognitive strategies enable learners to construct knowledge through self-regulation and reflective thinking. A substantial body of literature identifies four key metacognitive processes—planning, monitoring, evaluating, and reflection—as essential components of effective instruction. Planning involves goal setting, activation of prior knowledge, and strategic preparation (Dignath & Büttner, 2008; Pintrich, 2002; Zimmerman, 2000). Monitoring includes structured lesson sequences, explicit strategy instruction, and collaborative engagement that allow learners to track their understanding (Efklides, 2008; Tanner, 2012). Evaluating emphasizes self-questioning and assessment of conceptual understanding (Hattie & Donoghue, 2016), while reflection supports learners in assessing their performance and improving future learning (Tanner, 2012; Zimmerman, 2000). Collectively, these processes demonstrate that integrating metacognitive strategies across instructional phases enhances critical thinking, autonomy, and meaningful learning.

The integration of metacognition is further reinforced by national and global educational priorities. In the Philippine context, the K to 12 curriculum under Republic Act No. 10533 promotes learner-centered and inquiry-based instruction that fosters higher-order thinking skills, while the MATATAG Curriculum emphasizes the development of independent and critical learners. At the global level, Sustainable Development Goal 4 advocates for inclusive, equitable, and quality education that supports lifelong learning (United Nations, 2020). These frameworks highlight the importance of integrating metacognitive strategies to improve both learning outcomes and educational quality.

Despite strong theoretical and empirical support, the implementation of metacognitive strategies in classroom instruction remains inconsistent and often lacks systematic evaluation (Panadero, 2017). While teachers may incorporate elements of planning, monitoring, evaluating, and reflection, these components are not always explicitly structured or assessed in lesson design. Moreover, existing instruments primarily measure students' metacognitive awareness rather than evaluating how metacognitive strategies are embedded in instructional practices (de Bruin & van Gog, 2012). This creates a gap between theory and practice, limiting the effectiveness and scalability of metacognitive approaches in mathematics education.

In response, this study aims to analyze recent trends in metacognitive research and to develop a structured and validated evaluation instrument that assesses the integration of key metacognitive components—planning, monitoring, evaluating, and reflection—in mathematics lessons. The development of this instrument is significant in advancing sustainable and digitally responsive education, as it supports innovative, technology-enhanced, and learner-centered instructional practices. In digitally mediated learning environments, metacognitive strategies are essential in enabling learners to regulate their learning processes independently and effectively.

By providing an evidence-based evaluation framework, this study contributes to the improvement of instructional quality, curriculum innovation, and equitable learning opportunities. It aligns with the scope of sustainable education and digital transformation by promoting data-informed teaching practices, strengthening pedagogical design, and supporting the development of self-regulated learners equipped for lifelong learning in evolving educational contexts.

1.1. Statement of the Problem

This study examined metacognitive strategies in mathematics education and developed an evaluation instrument for assessing metacognitive-based lessons within sustainable and digitally supported learning environments.

Specifically, it sought to 1) determine the frequency and focus of foundational, empirical, and experimental studies on metacognitive strategies in mathematics education from 2020 to 2025 and 2) develop an evaluation instrument that measured the integration of planning, monitoring, evaluating, and reflection in mathematics instruction

2. Methodology

2.1. Research Design

This study employed a scoping review research design to systematically map the breadth, range, and nature of existing literature on metacognitive strategies in mathematics education. The scoping review approach was appropriate for synthesizing diverse sources of evidence, including foundational, empirical, and experimental studies, in order to provide a comprehensive overview of how metacognition is conceptualized and applied in instructional settings.

The design enabled the identification of key concepts, research trends, and gaps in the literature without limiting the review to narrowly defined research questions. Guided by a systematic and transparent process of searching, selecting, and analyzing studies, the scoping review ensured an organized and rigorous synthesis of available evidence. The review also served as the basis for developing an evaluation instrument for metacognitive-based lessons.

2.2. Review Framework / Protocol

The review was guided by the PRISMA-ScR framework (Tricco et al., 2018), which provides standardized procedures for conducting and reporting scoping reviews. The protocol involved several stages, including the identification of relevant studies through database searching, removal of duplicate records, title and abstract screening based on predefined eligibility criteria, full-text review of selected studies, and final inclusion of studies for analysis. This structured process ensured transparency, reproducibility, and methodological rigor, thereby strengthening the credibility of the findings and supporting the systematic development of the evaluation instrument.

2.3. Eligibility Criteria

Eligibility criteria were established to ensure the inclusion of relevant and high-quality studies. Included studies focused on metacognitive strategies in mathematics education, were published between 2020 and 2025, and consisted of peer-reviewed journal articles, conference papers, and scholarly publications with clear instructional or classroom-based applications. Studies were required to describe metacognitive processes such as planning, monitoring, evaluating, and reflection. Excluded studies included those not related to mathematics education, lacking explicit metacognitive components, purely theoretical papers without instructional application, and studies with insufficient descriptions of lesson design or implementation. These criteria ensured that only applicable and high-quality evidence informed the review.

2.4. Information Sources

Data were obtained from reputable academic databases to ensure the credibility and comprehensiveness of the study. The sources included ERIC, Scopus, Web of Science, Google Scholar, and Education Source. These databases provide access to a wide range of peer-reviewed and indexed publications relevant to mathematics education and metacognition.

2.5. Search Strategy

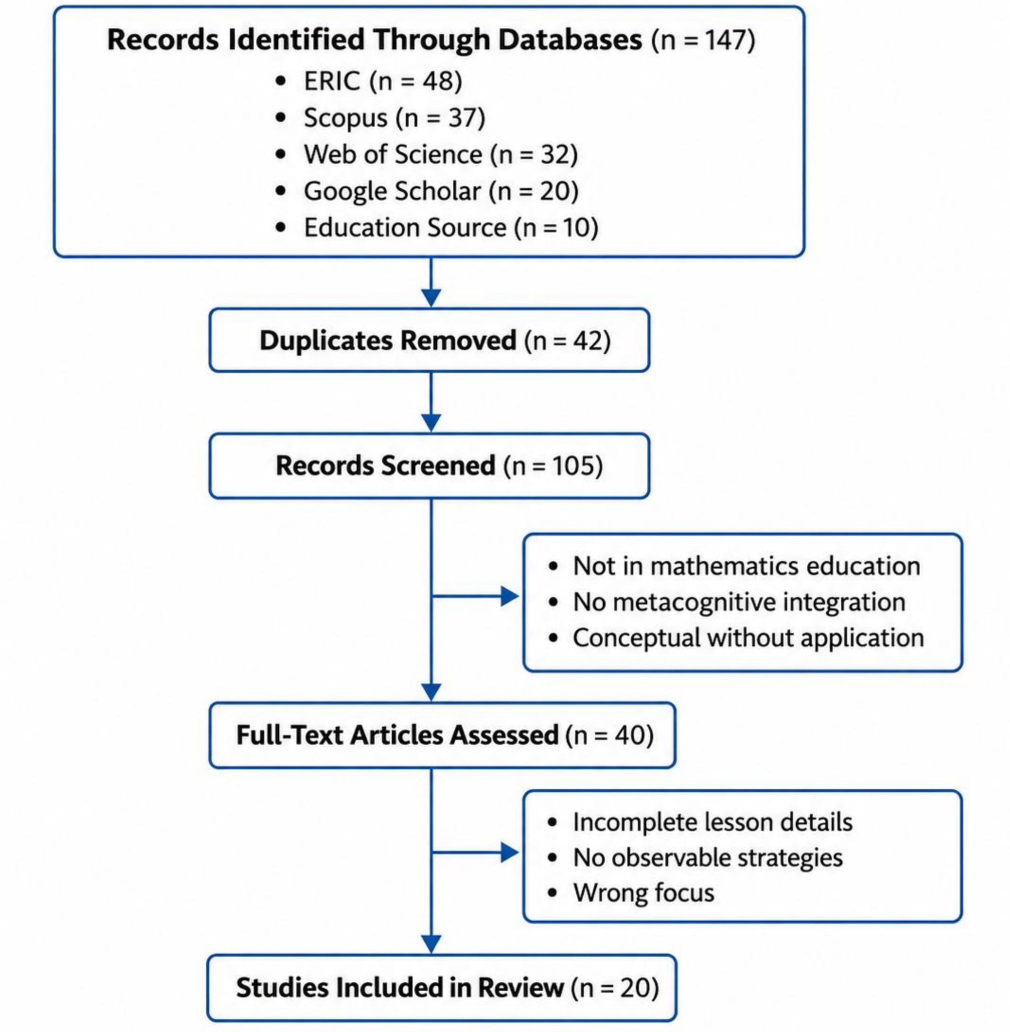
A systematic search strategy was applied using key terms such as “metacognition,” “metacognitive strategies,” “mathematics education,” “instructional practices,” and “learning strategies," combined using Boolean operators (AND, OR). The search was limited to studies published between 2020 and 2025 to ensure both comprehensive coverage and relevance to contemporary educational practices.

2.6. Study Selection

The study selection process followed a structured screening procedure. The initial search yielded 147 records across the selected databases (see Figure 1). After removing 42 duplicate studies, 105 unique records remained for title and abstract screening. During this stage, 65 studies were excluded due to lack of relevance, absence of metacognitive focus, or non-instructional nature, resulting in 40 studies for full-text review. A further 20 studies were excluded due to insufficient instructional detail or lack of observable metacognitive implementation. Consequently, 20 studies were included in the final analysis. This rigorous selection process ensured that the included studies represented high-quality and relevant evidence for analyzing metacognitive strategies and informing the development of the evaluation instrument.

Figure 1

Prisma Flow Diagram of Study Selection Process



2.7. Data Analysis / Synthesis

Data analysis involved both descriptive quantitative and qualitative thematic approaches aligned with the study objectives. For the first objective, studies were categorized into foundational, empirical, and experimental types. Frequency counts and percentage distributions were computed to determine the prevalence and focus of each category, providing an overview of research trends in metacognitive studies within mathematics education. For the second objective, a coding framework was developed based on the four metacognitive processes: planning, monitoring, evaluating, and reflection. Data extracted from lesson objectives, instructional activities, and pedagogical descriptions were systematically coded and analyzed. The thematic analysis followed the approach of Braun and Clarke (2006), involving familiarization with the data, initial coding, categorization, and theme development. Codes were grouped into themes representing metacognitive instructional practices, which informed the development of indicators for the evaluation instrument.

3. Results

3.1. Frequency of Studies on Metacognitive Strategies

To determine the frequency and distribution of studies on metacognitive strategies in mathematics education, selected literature was categorized into foundational, empirical, and experimental studies across four major instructional strategies. Table 1 presents the distribution of the 20 included studies.

Table 1
Frequency of Studies on Metacognitive Strategies Across Research Types

Metacognitive Strategy	*Foundational Theories*	*Empirical Studies*	*Experimental Studies*	*Total*
Think-Aloud Strategy	2	3	2	7
KWL Strategy	1	3	1	5
Self-Regulated Learning	2	3	2	7
Cooperative Learning	1	3	2	6
Total	6	12	7	20

The results show that self-regulated learning (SRL) and think-aloud strategies were the most frequently represented approaches, each accounting for 7 studies, followed by cooperative learning (6 studies) and KWL strategy (5 studies). Across research types, empirical studies (n = 12) were the most dominant, followed by experimental studies (n = 7) and foundational studies (n = 6), indicating that metacognitive research in mathematics education is primarily practice-oriented and classroom-based.

This distribution suggests a strong emphasis on applied research rather than purely theoretical development, aligning with trends reported in Scopus-indexed literature where metacognitive strategies are increasingly examined in real classroom environments to improve learner autonomy and problem-solving performance (e.g., de Bruin & van Gog, 2012; Panadero, 2017). The prominence of SRL and think-aloud strategies further reflects their strong empirical support in enhancing students' monitoring and regulation of cognition during mathematical tasks (Schraw, 1998; Zimmerman, 2000).The findings indicate that metacognitive research has shifted toward instructional implementation and learner-centered applications, although foundational studies remain essential in guiding theoretical framing.

3.2. Evaluation Indicators Basis for the Development of the Evaluation Instrument for Metacognitive-Based Lessons

To address the second objective, instructional practices extracted from the reviewed studies were synthesized into a structured set of evaluation indicators aligned with the four metacognitive processes: planning, monitoring, evaluating, and reflection. These indicators served as the foundation for the development of the evaluation instrument (see Appendix 1) for metacognitive-based lessons (MBL). Table 2 presents the finalized instrument indicators.

Table 2
Evaluation Indicators of Metacognitive-Based Lessons Aligned with Planning, Monitoring, Evaluating, and Reflection (Aligned to Rubric Sections A–D, 2000–2025 Sources)

Metacognitive Process	*Domain (Rubric Code)*	*Indicator*	*Role of Teacher*	*Role of Students*	*Source*
Planning	A1	Lesson objectives include planning skills such as goal setting and activating prior knowledge	Communicates learning goals, guides anticipation & planning	Understands goals and activates prior knowledge	Zimmerman (2000); Azevedo & Cromley (2004)
Planning	A2	Objectives show self-regulated learning skills	Guides students to plan and monitor learning processes	Plans strategies, monitors, evaluates own performance	Pintrich (2002); Dignath & Büttner (2008)
Planning	A3	Objectives clearly separate conceptual understanding from procedural skills	Emphasizes conceptual vs procedural focus	Differentiates conceptual vs procedural tasks	Hattie & Donoghue (2016)
Monitoring	B1	Lesson follows a clear sequence	Demonstrates stepwise lesson progression	Follows steps and monitors own learning	Young, Wu, & Yang (2014)
Monitoring	B2	Metacognitive strategies integrated throughout lesson	Ensures strategies are embedded	Applies strategies consistently	Dignath, Büttner, & Langfeldt (2008)
Monitoring	B3	Lesson explains metacognitive strategies & instructions	Models strategy use and explains application	Applies strategies as guided	Tanner (2012); Syaiful, Putra, & Wijaya (2022)
Monitoring	B4	Lesson includes clear reflection points	Provides structured reflective pauses	Pauses to reflect and self-assess	Efklides (2008)
Monitoring	B5	Learners take active role in making meaning	Encourages student-centered engagement	Actively constructs meaning	Reyes & Reyes (2023)
Monitoring	B6	Lesson includes cooperative/group learning	Facilitates peer discussion & collaborative reasoning	Participates in cooperative thinking	Jagals & van der Walt (2016); Macabecha, Santos, & Rivera (2024)
Monitoring	B7	Lesson includes assignments supporting reflection or practice	Assigns reflective or strategic tasks	Completes activities with reflection	Tanner (2012)

Table 2 continued

Metacognitive Process	*Domain (Rubric Code)*	*Indicator*	*Role of Teacher*	*Role of Students*	*Source*
Evaluating	**C1**	Activities activate prior knowledge & help set learning goals (e.g., KWL)	Facilitates organizers or KWL prompts	Activates prior knowledge & plans approach	Lai (2011); Ahmed & Hussain (2021)
Evaluating	C2	Activities include prompts to check understanding	Provides self-questioning prompts	Self-monitors comprehension	Zimmerman (2000); Reyes & Reyes (2023)
Evaluating	C3	Activities include reflection tasks	Guides reflection periods	Reflects on strategy use & learning outcomes	Tanner (2012); Efklides (2008)
Evaluating	C4	Activities allow students to explain thinking & ideas	Encourages articulation of reasoning	Explains thought processes & solutions	Jagals & van der Walt (2016); Chen & Tennyson (2019)
Evaluating	C5	Activities help distinguish concepts vs procedures (peer discussion)	Guides conceptual comparisons	Differentiates conceptual vs procedural reasoning	Hattie & Donoghue (2016); Macabecha, Santos, & Rivera (2024)
Reflection	D1	Lesson aligned with objectives and sequence	Ensures objective–activity alignment	Follows structure and reflects on goals	Young, Wu, & Yang (2014)
Reflection	D2	Lesson promotes learner-centered & self-regulated learning	Encourages SRL thinking	Monitors own learning & strategies	Zimmerman (2000); Dignath & Büttner (2008)
Reflection	D3	Lesson encourages reflection & appreciation of learning	Promotes reflective discussion	Reflects on learning experiences	Tanner (2012); Efklides (2008)
Reflection	D4	Metacognitive strategies consistently applied across lesson	Models reflection & monitoring	Applies strategies consistently	Zimmerman (2000); Syaiful, Putra, & Wijaya (2022)
Reflection	D5	Lesson is practical, clear, and appropriate for learners	Ensures clarity & accessibility	Engages with lesson effectively	Young, Wu, & Yang (2014)

3.2.1. A. Planning process (Domain A)

The planning component of the instrument focuses on how teachers design lessons that promote goal setting, prior knowledge activation, and cognitive preparation. The following indicators were developed:

A1: The lesson explicitly states learning objectives that guide students in setting goals for their learning.

A2: The lesson activates students' prior knowledge before introducing new concepts.

A3: The lesson distinguishes clearly between conceptual understanding and procedural skills.

These indicators reflect the planning dimension of metacognition, where learners prepare cognitively for learning tasks. This aligns with findings that goal-setting and prior knowledge activation are essential foundations of self-regulated learning (Azevedo & Cromley, 2004; Pintrich, 2002).

3.2.2. B. Monitoring process (Domain B)

The monitoring component evaluates how students track and regulate their understanding during instruction. The indicators include:

B1: The lesson is delivered in a logical and step-by-step sequence that supports cognitive monitoring.

B2: Metacognitive strategies are explicitly integrated throughout the lesson activities.

B3: The teacher models and explains how to use metacognitive strategies during problem-solving tasks.

B4: The lesson includes structured pauses for learners to check and reflect on their understanding.

B5: Students are given opportunities to actively construct meaning during learning tasks.

B6: The lesson incorporates cooperative learning activities that support peer monitoring of understanding.

B7: Assignments require students to monitor and evaluate their own learning process.

These indicators reflect monitoring as an ongoing regulatory process, consistent with literature emphasizing its role in supporting real-time cognitive adjustment and learning awareness (Dignath et al., 2008; Efklides, 2008; Tanner, 2012).

3.2.3. C. Evaluating process (Domain C)

The evaluating component focuses on how learners assess their understanding and reasoning after or during tasks. The indicators include:

C1: The lesson includes activities that activate prior knowledge and guide students in evaluating learning goals.

C2: The lesson provides self-questioning prompts to evaluate understanding.

C3: The lesson includes structured reflection tasks to assess learning outcomes.

C4: Students are encouraged to explain and justify their reasoning during problem-solving.

C5: Activities help students distinguish between conceptual and procedural understanding through comparison and discussion.

These indicators reflect evaluation as a cognitive judgment process, where learners assess correctness, understanding, and strategy effectiveness. This aligns with Scopus-based findings that evaluation enhances conceptual clarity and mathematical reasoning (Hattie & Donoghue, 2016).

3.2.4. D. Reflection process (Domain D)

The reflection component assesses how learners consolidate and evaluate their overall learning experience. The indicators include:

D1: The lesson ensures alignment between learning objectives and instructional activities.

D2: The lesson promotes self-regulated learning and learner autonomy.

D3: The lesson provides structured opportunities for students to reflect on their learning experiences.

D4: Metacognitive strategies are consistently applied throughout the lesson.

D5: The lesson is clear, practical, and appropriate for learners' cognitive level.

These indicators highlight reflection as a process of meaning-making and self-assessment, which is essential for long-term learning retention and autonomy (Tanner, 2012; Zimmerman, 2000). The analysis revealed that metacognitive instruction in mathematics education is consistently structured around four interrelated processes, which were operationalized into measurable indicators for evaluation purposes.

In the planning phase, findings show that effective mathematics lessons consistently begin with clearly stated learning objectives, activation of prior knowledge, and explicit distinction between conceptual and procedural understanding. These practices were translated into indicators (A1–A3), emphasizing goal-setting and cognitive preparation as essential foundations of learning. This supports Scopus-indexed findings that planning is a critical component of self-regulated learning, enabling learners to organize cognitive resources before engaging in tasks (Azevedo & Cromley, 2004; Pintrich, 2002).

In the monitoring phase, results indicate that effective instruction involves structured lesson sequencing, explicit modeling of strategies, embedded metacognitive prompts, and opportunities for cooperative learning. These were operationalized into indicators (B1–B7), highlighting the teacher's role in scaffolding while learners actively regulate their understanding. This finding aligns with research emphasizing monitoring as a continuous cognitive regulation process that enhances awareness and task performance in mathematics learning (Dignath et al., 2008; Efklides, 2008; Tanner, 2012).

For the evaluating phase, instructional practices were found to focus on self-questioning, reflection tasks, articulation of reasoning, and comparison of conceptual and procedural knowledge. These were developed into indicators (C1–C5). The findings suggest that evaluation is not limited to assessing correctness but involves deeper reflection on reasoning and understanding. This is consistent with Scopus-based literature indicating that evaluative processes strengthen conceptual understanding and mathematical reasoning (Hattie & Donoghue, 2016).

In the reflection phase, findings highlight that effective lessons ensure alignment of objectives, promote learner autonomy, encourage reflection, and maintain consistent use of metacognitive strategies. These were translated into indicators (D1–D5), emphasizing reflection as a consolidating process of learning. This supports the view that reflection enhances self-awareness and long-term retention of learning strategies (Tanner, 2012; Zimmerman, 2000).

The results demonstrate that metacognitive instruction in mathematics education is not a single strategy but a structured process consisting of planning, monitoring, evaluating, and reflection. These processes were consistently identified across studies and operationalized into measurable indicators that formed the basis for the evaluation instrument. However, the analysis also revealed variability in the explicitness of metacognitive integration across studies, suggesting the need for a standardized instrument to ensure consistent instructional evaluation.

The development of these indicators provides empirical grounding for assessing metacognitive-based lessons and contributes to improving instructional quality in mathematics education. It also supports the shift toward more structured, learner-centered, and evidence-based teaching practices aligned with contemporary educational demands.

4. Discussion

4.1. Frequency of Studies on Metacognitive Strategies

The findings indicate that empirical studies dominate the selected literature, followed by experimental and foundational studies. This distribution suggests that metacognitive strategies in mathematics education are primarily explored through classroom-based applications and intervention studies rather than theoretical discussions. This reflects a strong emphasis on practice-oriented research, consistent with Scopus-indexed literature highlighting the shift toward evidence-based instructional innovation in mathematics education (de Bruin et al., 2020; Panadero, 2017).

Among the identified strategies, think-aloud protocols and self-regulated learning emerged as the most frequently studied approaches across research types. Think-aloud strategies allow learners to externalize cognitive processes, making thinking visible and assessable, thereby supporting metacognitive awareness and problem-solving development (Chi & Wylie, 2014; Ericsson & Simon, 1993). SRL frameworks emphasize goal-setting, monitoring, and evaluation, which are strongly associated with improved academic performance in mathematics (Pintrich, 2002; Zimmerman, 2000). Recent studies further reinforce that SRL becomes more effective when supported by structured digital scaffolds and feedback systems, particularly in blended and online learning environments where learner autonomy is essential (Greene & Azevedo, 2010; Hadwin et al., 2018).

Although less frequent, cooperative learning and KWL strategies remain significant in promoting metacognitive engagement. Cooperative learning supports shared regulation of thinking through peer interaction, while KWL strategies structure knowledge activation and reflection processes (Johnson & Johnson, 2009; Lai, 2011). Collectively, these findings indicate that metacognitive strategies in mathematics education integrate both individual and social dimensions of learning. Importantly, these patterns provided the first empirical basis for instrument development, as they identified the most consistently documented metacognitive strategies across literature. These strategies were used as reference points in determining which instructional behaviors should be represented in the evaluation instrument.

4.2. Development of the Evaluation Instrument

The second objective focused on identifying instructional practices aligned with the metacognitive processes of planning, monitoring, evaluating, and reflection as the basis for the development of the evaluation instrument for Metacognitive-Based Lessons. The findings show that these four processes are consistently embedded in mathematics instruction, although their explicit integration varies across studies.

The evaluation instrument was developed through a systematic evidence-based process grounded in scoping review methodology (PRISMA-ScR). First, instructional practices were extracted from 20 selected studies focusing on metacognitive strategies in mathematics education. These practices were then analyzed using thematic analysis to identify recurring patterns across lesson design, instructional activities, and classroom interactions.

Through this process, instructional behaviors were coded and grouped into four metacognitive domains: planning, monitoring, evaluating, and reflection. These codes were not arbitrarily generated but were directly derived from empirical classroom-based evidence reported in Scopus-indexed and peer-reviewed studies. Each recurring instructional practice was then transformed into observable and measurable indicators, which became the items of the evaluation instrument.

Thus, the instrument is not a conceptual checklist but an evidence-derived measurement tool, where each indicator represents a validated instructional pattern consistently observed in the literature. This ensures that the tool reflects actual classroom practices rather than theoretical assumptions.

4.3. Interpretation of Metacognitive Processes (as Basis of the Instrument)

4.3.1. Planning

Planning practices include goal-setting, activation of prior knowledge, and differentiation between conceptual and procedural understanding. These align with self-regulated learning theory, where planning is the foundation of cognitive control (Azevedo & Cromley, 2004; Zimmerman, 2000). These findings directly informed the creation of planning indicators in the instrument.

4.3.2. Monitoring

Monitoring involves structured lesson sequencing, teacher modeling, embedded metacognitive prompts, and cooperative learning. These practices reflect ongoing cognitive regulation during learning (Efklides, 2008; Tanner, 2012). These patterns became the basis for monitoring-related items in the evaluation tool. In digital learning environments, monitoring is further strengthened through learning analytics, adaptive feedback, and interactive platforms that support real-time regulation of learning processes (Broadbent & Lodge, 2021).

4.3.3. Evaluating

Evaluating includes self-questioning, explanation of reasoning, and reflective tasks that distinguish conceptual and procedural understanding. These practices support deep learning and reasoning development (Hattie & Donoghue, 2016). Digital environments further enhance evaluative processes by allowing learners to revisit solutions, compare strategies, and receive automated feedback, strengthening metacognitive judgment (Greene & Azevedo, 2010).

4.3.4. Reflection

Reflection is embedded through structured reflection activities, alignment of objectives, and opportunities for learners to review learning experiences. Reflection supports long-term self-regulation and transfer of learning (Tanner, 2012; Zimmerman, 2000). In technology-enhanced classrooms, reflection is increasingly supported through e-portfolios, learning journals, and reflective dashboards that promote continuous self-assessment (Hadwin et al., 2018).

The findings further reveal that metacognitive instruction involves a shift in classroom roles. Teachers function as facilitators who model and scaffold metacognitive processes, while learners actively engage in self-regulated learning. This aligns with constructivist theory, which emphasizes learners as active knowledge constructors (Schraw, 1998). In digital learning environments, this role shift becomes more critical, as learners must independently manage their cognitive processes using digital tools and resources.

5. Conclusions

This study determined the frequency and application of metacognitive strategies in mathematics education and developed a evaluation instrument for metacognitive-based lessons through a scoping review of literature from 2020 to 2025. The study addressed two key objectives: (1) to determine the frequency and focus of foundational, empirical, and experimental studies on metacognitive strategies, and (2) to develop an evaluation instrument that assesses the integration of planning, monitoring, evaluating, and reflection in mathematics instruction.

First, the findings show that metacognitive strategies are predominantly represented in empirical studies, followed by experimental and foundational research. This indicates that metacognition is mainly explored in classroom-based and practice-oriented contexts, reflecting its applied relevance in mathematics education. This pattern aligns with Scopus-indexed research emphasizing the increasing shift toward evidence-based instructional practices and classroom implementation of metacognitive strategies (de Bruin et al., 2020; Panadero, 2017). Among the strategies, think-aloud protocols and self-regulated learning emerged as the most frequently studied approaches, confirming their strong theoretical and empirical foundation in supporting cognitive regulation and mathematical problem-solving (Ericsson & Simon, 1993; Zimmerman, 2000). Cooperative learning and KWL strategies also appeared consistently, supporting collaborative reasoning and structured activation of prior knowledge (Johnson & Johnson, 2009; Lai, 2011).

Second, the study confirms that metacognitive instruction in mathematics consistently integrates four core processes: planning, monitoring, evaluating, and reflection. These processes are operationalized in classroom instruction through goal-setting, prior knowledge activation, structured lesson sequencing, self-questioning, reflective tasks, and alignment of learning objectives with student experiences. These findings are consistent with established self-regulated learning frameworks and Scopus-indexed studies emphasizing metacognition as a cyclical process of cognitive control and reflection (Efklides, 2008; Hattie & Donoghue, 2016; Pintrich, 2002).

Third—and most importantly—the study developed the evaluation instrument through a systematic, evidence-based process. The instrument was constructed using a scoping review approach guided by PRISMA-ScR. Instructional practices were first extracted from 20 selected studies and then subjected to thematic analysis. Through this process, recurring instructional patterns were identified and coded according to the four metacognitive domains: planning, monitoring, evaluating, and reflection. These coded practices were then transformed into observable and measurable indicators, which formed the items of the evaluation instrument. Thus, each indicator in the tool is directly grounded in empirical evidence from peer-reviewed studies rather than theoretical assumption alone. This ensures that the instrument reflects authentic classroom practices documented in mathematics education research.Furthermore, the integration of metacognitive indicators into a structured instrument supports the goals of sustainable education and digital transformation, where learning systems increasingly require tools that promote learner autonomy, self-regulation, and adaptive thinking. In digitally mediated learning environments, such structured instruments are essential for ensuring instructional quality and consistency in promoting metacognitive engagement (OECD, 2023; UNESCO, 2021).

Metacognitive strategies are essential and systematically applicable components of mathematics instruction. More importantly, it establishes that a valid evaluation instrument can be developed through a structured scoping review and thematic synthesis of instructional practices, ensuring that assessment tools are evidence-based, context-relevant, and aligned with contemporary educational demands.

6. Implications within Sustainable Education and Digital Transformation

Within the scope of sustainable education and digital transformation, the findings underscore the importance of metacognitive strategies in developing lifelong learning competencies. Sustainable education promotes autonomy, adaptability, and reflective thinking, all of which are strengthened through metacognitive instruction. In online mathematics learning, self-regulated learning is particularly important because students are required to manage their learning more independently, and evidence indicates that self-regulated learning is associated with mathematics achievement in online contexts (Aviory et al., 2025; Lai & Hwang, 2016). Recent research further emphasizes that such environments require strong self-regulation frameworks to support meaningful engagement and persistence in technology-mediated instruction (Broadbent et al., 2021).

The evaluation instrument developed in this study directly contributes to this agenda by offering a structured, evidence-based tool for assessing metacognitive integration in mathematics instruction. It enables systematic evaluation of planning, monitoring, evaluating, and reflection processes, thereby supporting instructional quality assurance across both traditional and digital learning contexts. Digital assessment tools intended to evaluate higher-order cognitive skills require careful attention to validity, reliability, and cognitive-level alignment (Baudin, 2025).

In practical terms, the study has several key implications for mathematics education. First, mathematics teachers are encouraged to deliberately embed metacognitive processes—planning, monitoring, evaluating, and reflection—into instruction. Evidence from Scopus-indexed studies shows that structured metacognitive instruction enhances problem-solving ability, academic performance, and learner independence (de Bruin et al., 2020; Panadero, 2017; Schraw & Gutierrez, 2015). This is particularly critical in digital classrooms where learners are expected to regulate their own learning using technological tools. Second, curriculum developers and instructional designers may utilize the evaluation instrument as a framework for designing lesson plans, digital learning modules, and instructional materials. Because the instrument is grounded in empirical instructional practices, it ensures alignment between curriculum design and actual classroom implementation of metacognitive strategies, promoting more coherent and measurable learning experiences in both face-to-face and online modalities. Third, teacher education and professional development programs should prioritize strengthening teachers' capacity in both implementing metacognitive strategies and using structured evaluation tools. In digital learning environments, teachers increasingly function as facilitators of self-regulated learning rather than sole sources of knowledge (UNESCO, 2021; Winne & Azevedo, 2022; Zimmerman, 2000). Developing teacher competence in this area supports effective pedagogical adaptation to technology-enhanced education. Fourth, the evaluation instrument contributes to educational assessment practices by providing a standardized, evidence-based measure of metacognitive integration in mathematics instruction. This supports data-informed instructional improvement and enhances consistency in evaluating teaching quality across diverse learning environments, including digital and hybrid classrooms where conventional observation methods may be limited.

Fifth, students benefit from metacognitive-based instruction through improved self-regulation, critical thinking, and lifelong learning skills. These competencies are essential in both traditional and technology-enhanced learning contexts, particularly as learners are increasingly required to manage their own learning processes independently.

Finally, future research should focus on validating the instrument across different educational levels, cultural contexts, and digital learning environments. Further studies may also examine its predictive validity in relation to student achievement, engagement, and self-regulation in mathematics. This supports the broader agenda of sustainable education and digital transformation, where innovation in instructional design and assessment tools plays a central role in improving educational quality and equity. The study addresses a critical gap in mathematics education by translating empirical instructional practices into measurable indicators. In doing so, it provides a systematic, scalable, and evidence-based approach to evaluating metacognitive instruction in contemporary and future-ready learning environments.

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Appendix 1. Evaluation Instrument for Metacognitive-Based Lessons (MBL)

Purpose

This rubric is used to determine whether the lesson plan clearly and consistently integrates **research-based metacognitive strategies**.

Instructions for Experts
• Tick **Evident (✔)** if the feature is clearly observed in the lesson.
• Tick **Not Evident (✖)** if the feature is missing or unclear.
Scoring
Dichotomous: **Evident = 1**, **Not Evident = 0**

Section A – Planning and Objectives
This section checks whether the lesson objectives clearly include metacognitive skills and distinguish between understanding concepts and performing procedures.

No.	**Indicator**	**Evident (✔)**	**Not Evident (✖)**
A1	Lesson objectives include planning skills such as goal setting and activating prior knowledge.	☐	☐
A2	Objectives show self-regulated learning skills such as planning, monitoring, evaluating, and reflecting.	☐	☐
A3	Objectives clearly separate conceptual understanding from procedural skills.	☐	☐

Section B – Design of the Lesson
This section examines whether the lesson flow is well-organized and consistently applies metacognitive strategies.

No.	**Indicator**	**Evident (✔)**	**Not Evident (✖)**
B1	The lesson follows a clear sequence that allows learners to plan, monitor, and evaluate their learning.	☐	☐
B2	Metacognitive strategies are integrated throughout the lesson, not added as optional activities.	☐	☐
B3	The lesson clearly explains metacognitive strategies and gives instructions on how students should use them.	☐	☐
B4	The lesson includes clear reflection points for students.	☐	☐
B5	The lesson allows learners to take an active role in making meaning of the lesson.	☐	☐
B6	The lesson includes cooperative or group learning activities.	☐	☐
B7	The lesson includes an assignment that supports reflection or practice.	☐	☐

Section C – Learning Activities

This section focuses on how metacognitive strategies are applied through actual classroom activities.

No.	Indicator	Evident (✔)	Not Evident (✖)
C1	Activities activate prior knowledge and help students set learning goals (e.g KWL, organizers).	☐	☐
C2	Activities include prompts that help students check their understanding or performance.	☐	☐
C3	Activities include reflection tasks that help students evaluate their learning.	☐	☐
C4	Activities allow students to explain their thinking and ideas.	☐	☐
C5	Activities help students distinguish between understanding concepts and following procedures, often through peer discussion.	☐	☐

Section D – General Remarks

This section evaluates the overall quality, clarity, and usefulness of the lesson.

No.	Indicator	Evident (✔)	Not Evident (✖)
D1	The lesson is aligned with learning objectives, competencies, and content sequence.	☐	☐
D2	The lesson promotes learner-centered and self-regulated learning.	☐	☐
D3	The lesson encourages reflection and appreciation of learning.	☐	☐
D4	Metacognitive strategies are consistently applied across planning, lesson design, and activities.	☐	☐
D5	The lesson is practical, clear, and appropriate for the target learners.	☐	☐

Remarks:

Signature over Printed Name