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Global trends in metacognition research for mathematics learning: A systematic literature review

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Abstract

Although metacognition plays a pivotal role in mathematics learning, comprehensive studies mapping the global research landscape over the past five years remain scarce. This study addresses this gap by systematically examining global metacognitive research in mathematics education from 2021 to 2025. A systematic literature review (SLR) integrated with bibliometric analysis was conducted on 29 studies retrieved from six scientific databases (Scopus, ScienceDirect, PubMed, ERIC, Springer, and IEEE Xplore), following PRISMA 2020 guidelines. Two independent reviewers conducted screening; disagreements were resolved through discussion. Bibliometric visualization was performed using VOSviewer 1.6.20. Four main findings emerged: (1) research trends reveal theoretical maturity from basic studies toward cognitive-affective integration and technology-enhanced interventions; (2) Turkey and Indonesia lead research productivity (14% each), with Asian countries accounting for 55% of total output; (3) methodological approaches are balanced across qualitative, quantitative, and mixed-methods designs; and (4) metacognitive awareness significantly predicts mathematics achievement, operates within an integrated cognitive-affective system, shows individual differences, and is trainable through interventions, yet low-achieving students exhibit calibration problems. This study lays the groundwork for designing evidence-based metacognitive interventions and informing future research directions in mathematics education. Researchers and curriculum designers are encouraged to prioritize longitudinal designs, valid assessment instruments, and technology integration.

Keywords: bibliometric analysis; mathematics; metacognitive; systematic review

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Introduction

Metacognition is the awareness of students regarding the regulation of their own thinking processes. Metacognition has emerged as an important factor in successful mathematics learning. Students who effectively use metacognitive strategies show superior problem-solving skills, greater perseverance in completing challenging tasks, and improvements in mathematics achievement (Aydın & Özgeldi, 2024). In mathematics education today, metacognition extends beyond knowledge acquisition to include self-monitoring, evaluation, and strategic adjustment of learning approaches (Baumanns & Rott, 2023).

Recent global research increasingly recognizes metacognition as a fundamental component in developing mathematical competence. Research conducted by Alzahrani (2022), showed that metacognition significantly affect students' motivation, self-regulation, and academic performance in mathematics. Furthermore, metacognitive skills serve as a predictor of success in mathematical problem solving, especially in non-routine tasks that require higher order thinking (Novakova, 2024). Despite the increasing research interest in this area, the relationship between metacognition and various aspects of mathematics learning including gender differences, cognitive styles, technology integration, and affective factors is still poorly explored through a comprehensive systematic review.

The period from 2021 to 2025 has witnessed substantial growth in metacognitive research, particularly in mathematics education. This development reflects a diversity of methodological approaches, geographical contexts and thematic foci. However, the existing literature lacks a systematic synthesis that maps the global research landscape, identifies patterns of collaboration, and highlights emerging trends in this important domain. Such a synthesis is critical to understanding how metacognitive research has evolved, which regions are most actively contributing to the field, and what methodologies dominate in investigating students' metacognitive processes.

This systematic literature review (SLR), integrated with bibliometric analysis addresses this gap by providing a comprehensive examination of metacognitive research in mathematics education from 2021 to 2025. Using PRISMA 2020 guidelines and leveraging VOSviewer for visualization, this study offers a narrative synthesis and data-driven insights into the research dynamics, thematic evolution and collaborative networks in this field.

This study aims to systematically analyze and synthesize global research on metacognition in mathematics education through several research questions, namely:

RQ1 : How has the research trend and potential for students' metacognitive development in mathematics education evolved from 2021 to 2025?

RQ2 : Which countries show the highest research output on student metacognition in mathematics education, and what factors contribute to the emergence and urgency of research in these areas?

RQ3 : What methodological approaches are most frequently used in researching students' metacognition in mathematics education based on current literature?

RQ4 : What are the main findings of current research relevant to the measurement and development of students' metacognitive skills in mathematics education?

By answering these research questions, this study will contribute to the study of mathematics education by identifying knowledge gaps, highlighting methodological trends, revealing geographical patterns in research productivity, and synthesizing empirical findings that inform educational practice and policy. The integration of SLR with bibliometric analysis provides a unique dual perspective, offering a synthesis of substantive content and quantitative insights into research networks and citation patterns.

The significance of this study lies in its potential to guide future research directions, inform curriculum development, and support teachers in designing metacognitive-focused interventions. As mathematics education continues to evolve in response to technological advances and changing pedagogical paradigms, an understanding of how metacognition has been researched globally is crucial to advancing theoretical knowledge and practical applications in the classroom environment.

Methods

Research design

This study applied a Systematic Literature Review (SLR) approach integrated with bibliometric analysis with the aim of mapping the metacognitive research landscape in the context of mathematics learning as a whole. The research stages were carried out systematically following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) stages developed by Page et al., (2021), starting with identifying literature sources, screening based on predetermined criteria, to conducting in-depth analysis of publications that meet the eligibility requirements.

Screening and selection were conducted independently by two reviewers. Disagreements were resolved through discussion until consensus was reached. No automation tools beyond standard database filters were employed during the initial screening phase.

To strengthen the objectivity and depth of analysis, this research utilizes Vosviewer software version 1.6.20 as the main instrument in visualizing researcher collaboration networks, keyword occurrence patterns, and citation structures between publications (Eck & Waltman, 2023). The VOSviewer analysis used a minimum keyword co-occurrence threshold of 2, with association strength as the normalization method. This dual approach was designed to produce two dimensions of findings, namely: (1) A systematic narrative that summarizes the substance of metacognition research; (2) A data-driven visual representation that reveals thematic dynamics, topic evolution, and traces of global research collaboration over the span of 2021 to 2025.

The bibliometric analysis component uses scientometric techniques to quantitatively assess publication trends, identify prolific countries and institutions, examine methodological preferences, and detect emerging research themes through shared keyword analysis. This combination of qualitative synthesis and quantitative bibliometric mapping provides a comprehensive understanding of the content and structure of metacognitive research in mathematics education.

Search and selection of papers

This SLR focused on articles published between January 2021 and December 2025, with the aim of examining the global state of the art in metacognitive research in mathematics. It is acknowledged that 2025 data may be incomplete due to publication lag; studies included from 2025 are those that had been formally published or accepted for publication (including early-access and ahead-of-print articles) at the time of the database search. The article search in this study used six reputable electronic databases, consisting of Scopus, ScienceDirect, PubMed, ERIC, Springer, IEEE Xplore. The selection of these six databases was based on their comprehensive coverage of publications in education and mathematics, as well as accessibility to high-quality peer-reviewed articles (Mongeon & Paul-Hus, 2015). Searches were conducted on December 10, 2025. The same search string was applied consistently across all six databases to ensure uniformity in the retrieval process, although minor syntactic adaptions were made where required by individual platform interfaces (e.g., field code differences in PubMed and ERIC).

This search was conducted using specific string queries and following the inclusion and exclusion criteria adapted from Lina et al., (2025), which has been modified by the author to suit the research to be carried out. The details of information sources and specific search criteria for this research can be seen in Table 1 below.

Table 1. Information sources and search criteria for SLR

Information Source	Aspect	Description
Scopus, ScienceDirect, PubMed, ERIC, Springer, IEEE Xplore	Time frame	January 2021 to December 2025 (Inclusive of early-access and ahead-of-print articles published by the search data; 2025 data are acknowledged as potentially incomplete due to publication lag).
	Searching strings	Scopus-ScienceDirect-PubMed-ERIC-Springer-IEEE Xplore: TITTLE-ABS-KEY= ("metacognition") AND ("mathematics" OR "mathematics education" OR "mathematics learning" OR "mathematics teaching"). Search conducted on: December 10, 2025.
	Inclusion Criteria (IN)	IN1 : Journal article IN2 : This study was written in English IN3 : The study is not listed in any other database (avoiding duplication) IN4 : The study comes with full text that can be accessed at IN5 : This study only focuses on the subject areas “Social sciences” and “Mathematics” IN6 : This study is specific to the keywords “Metacognition”, “Mathematics”, ‘Students’, and “Mathematics Education” IN7 : This study covers empirical research, case studies, innovations and new technologies, training, and curriculum development.
	Exclusion	EX1 : Conference paper, Book chapter, Review,

Information Source	Aspect			Description
	Criteria (EX)			Conference review, Book, Erratum, Editorial, Note
		EX2	:	Study not written in English
		EX3	:	The study is listed in another database
		EX4	:	The study is not provided with full text that can be accessed
		EX5	:	The study does not focus on subject areas other than “Social sciences” and “Mathematics”
		EX6	:	This study is not specific to keywords other than “Metacognition” and “Mathematics”
		EX7	:	This study does not include literature review, meta-analysis, bibliometric analysis

Source: Lina et al., (2025), then modified by the authors.

Table 1 shows how the SLR-related information search was conducted in this study, which starts from making restrictions related to the range of 2021 to 2015, searching using TITTLE-ABS-KEY= ("metacognition") AND ("mathematics" OR "mathematics education" OR "mathematics learning" OR "mathematics teaching"). Table 1 also displays the inclusion-exclusion criteria loaded in the digital database for data search.

Data collection techniques

In this study, data collection was conducted based on the PRISMA stages, which aim to facilitate specifications in identifying, screening and selecting relevant research. In detail, the stages in this research based on PRISMA can be seen in Figure 1 below:

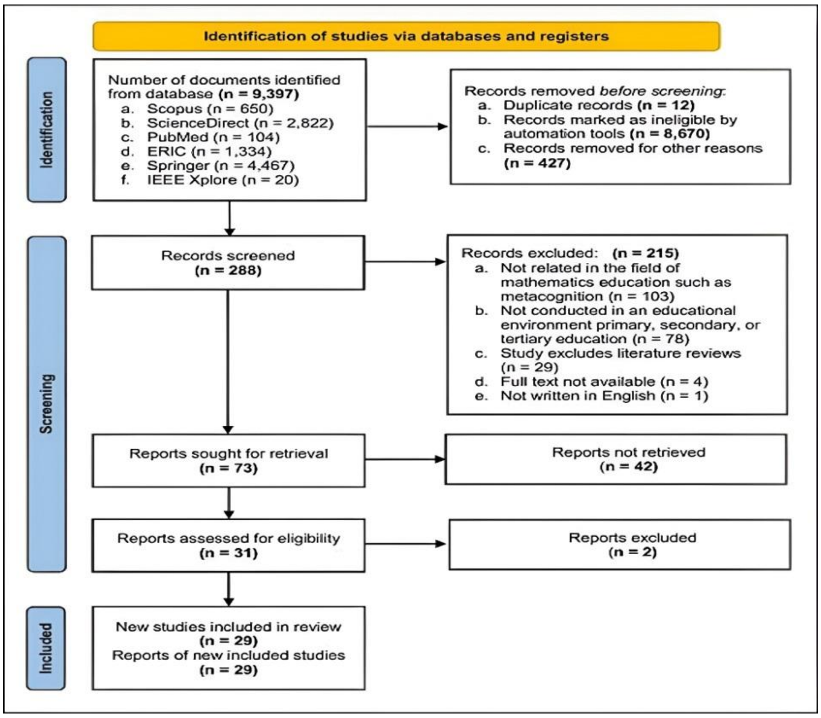

Figure 1. PRISMA framework for "Metacognition in Mathematics"
(Source: Modified by the authors)

Figure 1 explains the stages of PRISMA starting from identification, screening, to inclusion. A comprehensive search was conducted in six databases namely Scopus (n = 650), ScienceDirect (n = 2,822), PubMed (n = 104), ERIC (n = 1,334), Springer (n = 4,467), and IEEE Xplore (n = 20), which resulted in a total of 9,397 records. After removing duplicates and applying automated filtering tools to filter out irrelevant records, 288 articles were screened based on title and abstract. Of these, 215 records were excluded as they did not meet the inclusion criteria. Full-text retrieval attempts were made for 73 documents; 42 were not retrieved and 2 were excluded after full-text assessment. The remaining 29 documents met all inclusion criteria and were included in this systematic review for data extraction and analysis.

Results

Research trends and potential developments (2021-2025)

The distribution of metacognitive research in mathematics education from 2021 to 2025 shows a pattern of fluctuation in the results of scientific publications. Based on the results of data processing that has been carried out from six databases, the distribution of metacognitive research, can be seen in Figure 2 below.

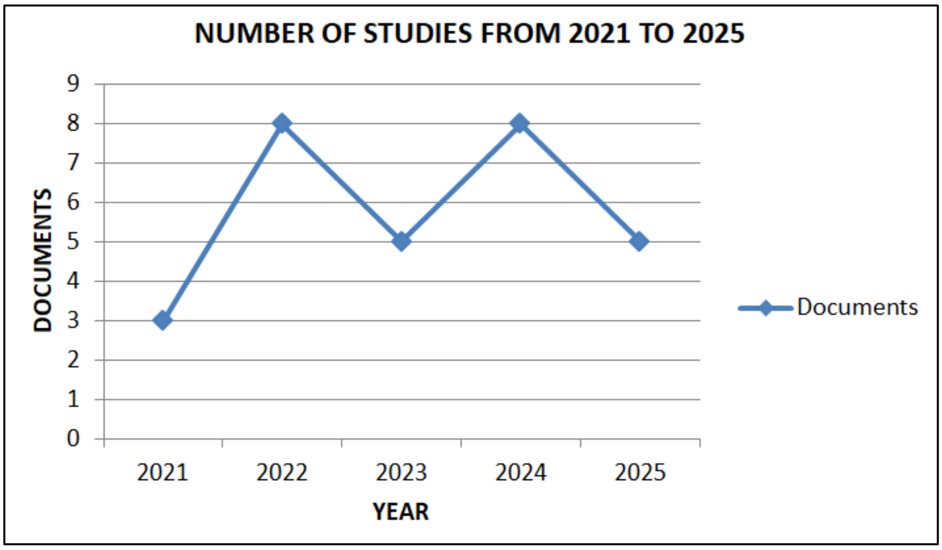

Figure 2. Distribution of research on “Metacognition in Mathematics” between 2021-2025

Based on Figure 2 The distribution of research on metacognition in mathematics education has ups and downs, there are increases and decreases for each year. The lowest recorded publication count occurred in 2021 with only 3 publications. For 2022 and 2024, research related to metacognition increased to 8 publication documents each; a relative decline was observed in 2023 (5 documents). The figure for 2025 (5 document) should be interpreted with caution, as this likely represents only those articles formally published or available as early access at the time of data collection-further publications from 2025 are expected as the year’s pipeline matures. This pattern of fluctuation may also reflect shifting research priorities, saturation of certain metacognitive themes, or delays in the publication pipeline. Despite this fluctuation, the 29 articles collectively demonstrate a continuing scientific interest in understanding how students monitor, organize, and reflect on their mathematical thinking.

Geographical and thematic distribution of research

Based on the analysis of 29 studies, there is some distribution of metacognitive research contributions in mathematics education by country. This distribution is clearly presented in Figure 3 below:

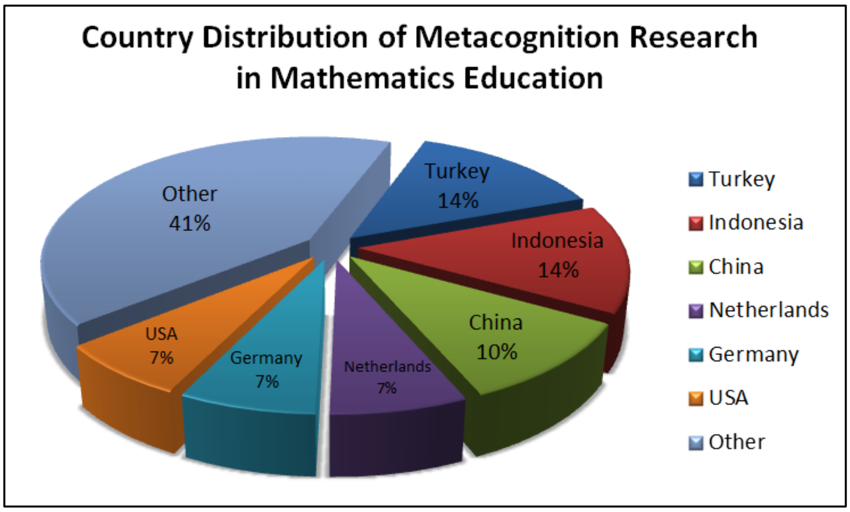

Figure 3. Country distribution of metacognition research in mathematics education

Based on Figure 3, and with country attribution determined based on the corresponding author's institutional affiliation, Turkey and Indonesia emerged as the most productive countries, each contributing four studies (14% of the total output). The preponderance of metacognitive-related studies conducted in these two countries is likely due to the continuous investment in mathematics education research and an established research community focused on metacognitive interventions. Asian countries accounted for 55% of the total output, with Turkey (14%), Indonesia (14%), China (10%), and other Asian countries contributing the remainder. A full breakdown of the country distribution, including European contributions (Netherlands 7%, Germany 7%), is presented in Figure 3. It is important to note that the concentration of English-language publications may underrepresent research from non-English-speaking European countries.

The analysis conducted using VOSviewer displayed the keyword co-occurrence of the 29 included studies, and provided three main clusters which can be seen in Figure 4 below.

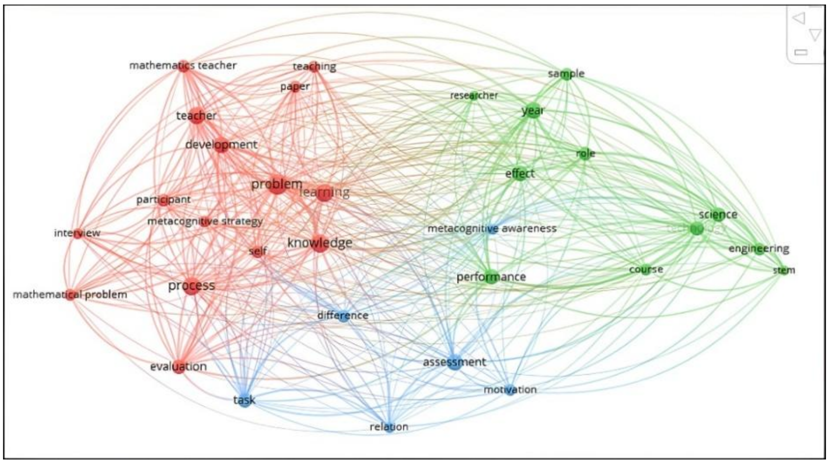

Figure 4. Network visualization: Co-occurrence analysis using VOSviewer of metacognition research in mathematics education

Based on Figure 4 it can be seen that the red cluster is centered on "mathematics teacher", "problem", "mathematics strategy", 'process', "knowledge", this cluster represents research that focuses on pedagogical aspects, thinking processes, and the development of metacognitive knowledge. The green cluster is dominated by "stem", 'engineering', "performance", this cluster reflects research that focuses on learning outcomes and student competencies. The blue cluster shows the keywords "metacognitive awareness", 'motivation', "assessment", which represent the affective dimension and metacognitive awareness. The central position of the "metacognitive awareness" node indicates its role as a connecting construct between pedagogical aspects (red) and student outcomes (green). Larger nodes such as "metacognitive", "math education", "problem solving" indicate a higher frequency of occurrence in the literature. This confirms that these are the dominant themes in mathematics metacognitive research in 2021-2025.

In addition, the overlay visualization also displays the temporal evolution of research by publication year 2021-2025, which can be seen in Figure 5 below:

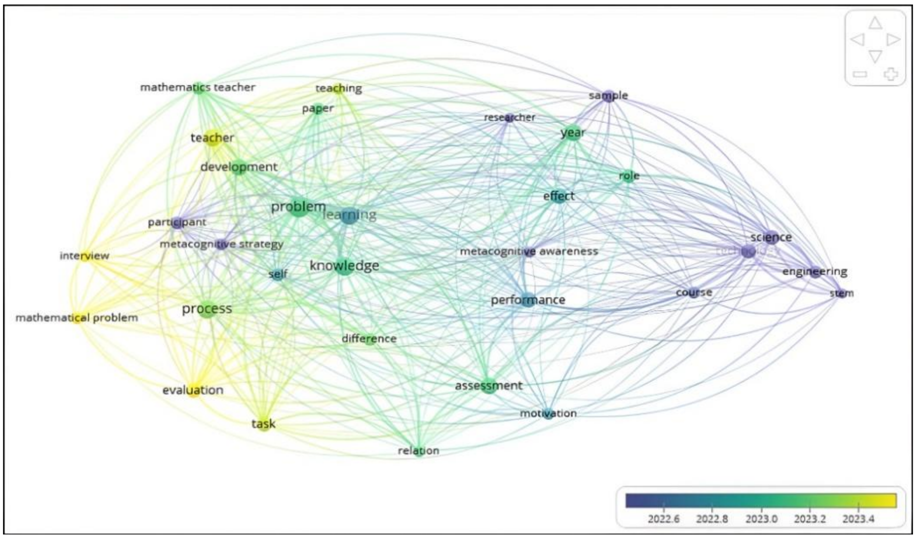

Figure 5. Overlay visualization: Temporal evolution using VOSviewer of metacognition research in mathematics education

Figure 5 shows how the visualization of temporal evolution using VOSviewer based on publication year. Purple nodes centered on the keywords "science," "engineering," "STEM," and "metacognitive awareness" dominate the early period (2021-2022), indicating that metacognitive research began from an interdisciplinary STEM context with a focus on metacognitive awareness as a basic construct. Colored nodes with the keywords "performance," "motivation," "learning," "self-regulation," and "achievement" indicate a shift toward exploring metacognitive relationships with learning outcomes and affective-motivational factors (2022-2023). Green nodes with the keywords "problem," "knowledge," "assessment," "process," "mathematics teacher," and "development" indicate a consolidation phase where research began to focus on the problem-solving process, the role of the teacher, and the development of metacognitive assessment instruments (2023-2024). Yellow-colored nodes with the keywords "mathematical problem," "evaluation," "teacher," and "teaching" indicate a recent trend focusing on concrete teaching practices and evaluation of learning (2024-2025, noting that 2025 data are partial).

The bibliometric analysis through VOSviewer also displays a density map visualization that shows the thematic concentration of research with color gradations, as shown in Figure 6 below:

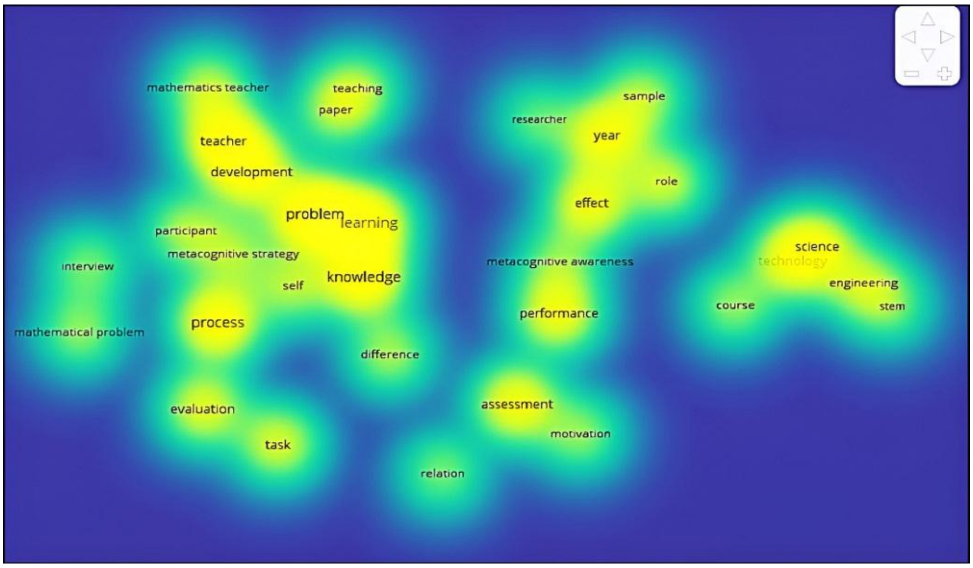

Figure 6. Density visualization: Thematic concentration using VOSviewer of metacognition research in mathematics education

Based on Figure 6, "mathematics teacher," "problem," and "knowledge" are highly researched and belong to the most mature themes. Emerging themes such as "evaluation," "task," and specific instructional approaches still have wide exploration space. The hotspots are evenly distributed across multiple areas, indicating that metacognitive research is a multi-faceted field that cannot be reduced to a single dimension. The full VOSviewer parameters and output metrics are available upon request from the corresponding author.

Methodological approaches in metacognitive research

A total of 29 included studies used various methodological approaches to investigate metacognitive processes in mathematics education. The following Table 2 presents the distribution of research methods based on the findings obtained from the 29 studies:

Table 2. Distribution of research methodologies

Research Methods	Number of Studies	Percentage
Qualitative	11	37,9%
Quantitative	10	34,5%
Mixed Methods	8	27,6%
Total	**29**	**100%**

Based on Table 2, it is known that qualitative methods constitute the largest proportion (37.9%), followed by quantitative approaches (34.5%), and mixed methods (27.6%). The relatively balanced distribution reflects the complexity of metacognitive phenomena that require both in-depth exploration and statistical validation. The balance also reflects the methodological maturity of the field. However, it should be noted that qualitative research may be underrepresented in certain databases (e.g., IEEE Xplore), which could partially influence this distribution. The following presents the results obtained based on th research methods of the 29 included studies:

1. **Qualitative studies (n = 11)**
   These investigations mostly used critical thinking protocols, clinical interviews, and case study designs to capture the nuances of students' metacognitive processes during problem solving. Research conducted by Altinay & Ünver (2024), Baumanns & Rott (2023), and Garcia-Moya et al., (2024), illustrate how a qualitative approach reveals detailed metacognitive regulation strategies, including planning, monitoring, and evaluation that a third student uses to deal with mathematical challenges.
2. **Quantitative study (n = 10)**
   This research effort used validated instruments to measure metacognitive awareness, assess the relationship between metacognition and achievement, and test predictive models. Research conducted by Bulut (2021), Chen et al., (2025), and Wahba et al., (2022), showed how quantitative methods allowed researchers to identify significant correlations between metacognitive awareness and learning approaches, test anxiety, and attitudes towards STEM.
3. **Mixed methods study (n = 8)**
   This investigation combines the strengths of two approaches, where quantitative data is used to establish patterns and qualitative data is used to explain underlying processes. Research conducted by Aydın & Özgeldi (2024), Moustakas & Gonida (2023), and Zhang et al., (2024), illustrates how mixed methods provide a comprehensive understanding of metacognition by triangulating statistical relationships with rich descriptive accounts of student experiences.

Key findings from recent research

Based on the analysis conducted in filtering data through six reputable electronic databases, consisting of Scopus, ScienceDirect, PubMed, ERIC, Springer, 29 documents were found that were relevant to the objectives of this study. The documents are presented in Table 3 which provides a comprehensive overview of all the studies, their methodologies and key findings, as Table 3 follows.

Table 3. A comprehensive overview of included studies on metacognition in mathematics education

No.	Author	Country	Methods	Research Results
1	Altinay & Ünver, (2024)	Turkey	Qualitative	Eighth grade students demonstrated metacognitive regulation skills categorized into prediction, planning, monitoring, and evaluation during a problem-solving task.
2	Almeida & Castro (2023)	Brazil	Qualitative	The proposed instrument effectively identified students' metacognitive strategies in mathematical modeling activities, emphasizing the teacher's role in this process
3	Alzahrani (2022)	Saudi Arabia	Qualitative	There is a significant relationship between metacognition and motivation, which enhances students' independent learning in mathematics
4	Arslan & Finn (2023)	Netherlands	Qualitative	Encouragement effectively encourages students to exert more effort, students do not significantly improve performance, indicating that students often self-regulate their efforts based on their perceived knowledge and abilities
5	Aydın & Özgeldi (2024)	Turkey	Mixed-method	Improving metacognitive skills can help reduce test anxiety and improve math performance
6	Baumanns & Rott (2023)	Germany	Qualitative	Metacognitive behavior can serve as a new perspective for assessing qualities that pose problems beyond just the product of the process
7	Bulut (2021)	Turkey	Quantitative	There was a positive correlation between metacognitive awareness and deep/strategic learning approaches, while no significant relationship was found with surface learning
8	Chen et al., (2025)	United States	Quantitative	Low-performing students showed more self-confidence than their higher-performing peers
9	Garcia-Moya et al., (2024)	Spain	Qualitative	Polya's guided stages and the use of technology can improve students' metacognition and confidence
10	Grenell et al., (2025)	USA	Mixed-method	Misconceptions led to high confidence in wrong answers. It found limited cross-topic associations in metacognitive monitoring, suggesting that children's confidence in one area cannot reliably predict their performance in other areas
11	Hawrot et al., (2025)	Germany	Quantitative	The analysis does not support the self-knowledge or optimal margin hypotheses commonly discussed in metacognitive research

No.	Author	Country	Methods	Research Results
12	Henra et al. (2024)	Indonesia	Qualitative	Both female and male students used metacognitive knowledge and regulation strategies, with female students using the 'guessing' strategy more frequently than their male counterparts
13	Henra et al., (2025)	Indonesia	Qualitative	Female students used all metacognitive components, including declarative, procedural, and conditional knowledge, as well as metacognitive regulation, in solving statistical problems
1	Liu et al., (2022)	China	Qualitative	Students' learning motivation significantly influences and can predict their STEM attitudes, with metacognitive level serving as a positive mediator in this relationship
15	Moustakas & Gonida (2023)	Thessaloniki	Mixed Method	High-achieving students in mathematics have diverse motivational profiles, which are associated with a range of metacognitive and emotional characteristics, challenging the idea of high achievers as a homogenous group
16	Novakova (2024)	Czech Republic	Quantitative	Success rates in solving mathematical problems, especially non-routine ones, were low, suggesting a need for improved understanding and problem-solving strategies among students. The researcher concluded that the importance of metacognition as a predictor of learning success, suggests that improving metacognitive skills can improve student performance in mathematics
17	Pirrone et al., (2022)	Italy	Quantitative	Students generally experienced less anxiety in distance learning, but those who preferred hands-on learning showed better mental state and metacognitive awareness, suggesting the need for targeted interventions to address anxiety
18	Rican et al., (2022)	Republik Ceko	Mixed-method	The assessment of confidence in students is influenced by their beliefs about intelligence, affecting their self-efficacy and motivation towards mathematics
19	Seferian et al., (2021)	Uruguay	Quantitative	Of all the performance-enhancing strategies, volitional and metacognitive strategies had the most significant and lasting impact, highlighting the importance of targeting emotional and motivational factors in learning
20	Subba et al., (2025)	Thailand	Mixed-method	The instructional model made the learning process interesting and different from students' previous experiences, with positive feedback on collaborative group work
21	Suliani et al., (2024)	Indonesia	Quantitative	Students' mathematical confidence significantly influenced their metacognitive knowledge when solving geometric problems, suggesting that higher mathematical confidence correlated with better metacognitive scores
22	Sutama et al., (2021)	Indonesia	Qualitative	Both cognitive styles involve different problem-solving processes, with FI students being more

No.	Author	Country	Methods	Research Results
				autonomous and able to make important decisions
23	Termaat (2024)	Australia	Qualitative	Comparative tests such as NAEP although characterized as low stakes, significantly impact school reputation and reinforce social inequities
24	Vreeze-Westgeest & Vogelaar (2022)	Netherlands	Mixed-method	Significant improvements in working memory and metacognition, with intelligence predicting verbal and visual working memory, but no meaningful relationship found between intelligence and metacognitive knowledge
25	Vuorre & Metcalfe (2022)	USA	Quantitative	Metacognitive resolution was significantly correlated with performance in multiple-choice mathematics testing, suggesting that this relationship may be influenced by guessing behaviorp
26	Wahba et al., (2022)	Jordan	Quantitative	STEAM activities significantly increased the level of math metacognitive awareness among primary stage students compared to traditional teaching methods
27	Wang et al., (2022)	China	Mixed-method	The implementation of a math metacognitive intelligence assessment system resulted in a slight improvement in students' academic performance, with mean scores increasing by 0.454 after the intervention
28	Yıldız & Öztürk (2023)	Turkey	Quantitative	There was a positive and significant relationship between sixth graders' metacognition and their performance in problem-solving, with academic success in math and mother tongue acting as mediators in this relationship
29	Zhang et al., (2024)	China	Mixed-method	Improvements in metacognitive knowledge and monitoring were positively correlated with improvements in mathematical modeling skills, suggesting that fostering metacognition can improve students' critical thinking and modeling abilities

Table 3 presents in detail the 29 studies found. Each study is explained which country it came from, the methods used, as well as how the results of the research. Broadly speaking, the 29 metacognitive-related studies found have interrelated relationships, both with mathematics achievement, problem solving and instructional approaches. In more detail, the results of this research related to these 29 studies are described below:

1. **Metacognition and math achievement**

   Several studies confirm that there is a significant positive relationship between metacognitive awareness and math achievement. Research conducted by Novakova (2024), identified metacognition as a predictor of learning success, especially in the context of non-routine problem solving. This statement is in line with the results of research by Suliani et al., (2024), where students' mathematical beliefs significantly affect metacognitive knowledge, with higher beliefs correlating with superior metacognitive scores. Zhang et al., (2024), showed that improved metacognitive knowledge and monitoring were positively correlated with improved mathematical modeling skills.

2. **Metacognition and affective factors**
   Research reveals a complex interaction between metacognition and affective dimensions of mathematics learning. Aydın & Özgeldi (2024), established that improving metacognitive skills can reduce test anxiety while improving student performance. Alzahrani (2022), also identified a significant relationship between metacognition and motivation in promoting independent learning. Research conducted by Liu et al., (2022), also found that metacognitive levels were able to mediate the relationship between learning motivation and STEM attitudes.
3. **Metacognitive strategies and problem solving**
   A qualitative investigation revealed a detailed taxonomy of metacognitive strategies that students use during mathematical problem solving. Altinay & Ünver (2024), categorized regulation skills into prediction, planning, monitoring, and evaluation phases. Garcia-Moya et al., (2024), showed how Polya's problem solving stages combined with technology can improve metacognitive functions and self-confidence. Almeida & Castro (2023), who conducted instrument development research with the aim to identify metacognitive strategies in mathematical modeling, revealed how students navigate the complex process of translating real-world situations into mathematical representations.
4. **Individual differences in metacognition**
   Research identifies important individual variations in metacognitive processes. Research conducted by Henra et al., (2024), and Henra et al., (2025), stated that gender differences show that female students are much more competitive in using metacognitive components of comprehension while using different strategy patterns, for example, using more guessing strategies. Research conducted by Chen et al., (2025), shows that low-achieving students have metacognitive calibration problems, displaying excessive self-confidence compared to their actual performance. Cognitive style can influence metacognitive approaches, with field-independent students showing greater autonomy in decision making during problem solving (Sutama et al., 2021).
5. **Interventions and instructional approaches**
   Several studies examined interventions designed with the aim of increasing metacognitive awareness and skills. Wahba et al., (2022), in their study showed that STEAM activities were significantly able to increase metacognitive awareness compared to traditional teaching. This statement is supported by Wang et al., (2022), who found that the metacognitive intelligence assessment system was able to produce measurable improvements in academic performance. Seferian et al., (2021), found that volitional and metacognitive strategies produced the most significant and lasting performance improvements. Research conducted by Subba et al., (2025), proposed a constructivism-based learning model capable of improving metacognition and problem solving skills through collaborative group work.

Discussion

This SLR integrated with bibliometric analysis reveals important insights into the global metacognitive research landscape in mathematics education from January 2021 to December 2025. The findings not only shed light on what has been learned, but more importantly on the theoretical maturity, methodological sophistication and challenges that continue to define this domain. The following discussion interprets the patterns and implications emerging from the results presented above.

Research trends and geographical concentration

The fluctuation in annual publication counts reflects deeper disciplinary dynamics. The relatively low output in 2021 may be attributed to disruptions caused by the COVID-19 pandemic on research timelines, while peaks in 2022 and 2024 suggest a recovery and consolidation phase in metacognitive research productivity. The preponderance of studies from Turkey and Indonesia (14% each) and the broader dominance of Asian countries (55%) are not merely bibliometric observations but reflect deeper educational realities: these regions face intense pressure from international assessment (PISA, TIMSS) and are undergoing rapid curriculum reforms that emphasize 21st-century competencies (Aydın & Özgeldi, 2024; Novakova, 2024). Metacognitive research in these contexts is often policy-driven rather than purely scientific, which may explain both its productivity and its pragmatic orientation toward intervention and achievement. Conversely, the relative paucity of research from other regions creates significant knowledge gaps, and the current evidence base cannot be considered globally representative.

The paradox of metacognition development: Trainability versus transfer

Research conducted by Wahba et al., (2022), Wang et al., (2022), Subba et al., (2025), found that metacognitive skills were shown to be trainable through targeted interventions, but unfortunately the transfer of these skills across different mathematical domains remains problematic. Grenell et al., (2025), provided important evidence that students' metacognitive confidence in one area of mathematics does not reliably predict performance in another, suggesting domain specificity rather than generalization. This finding challenges the assumption implicit in many intervention studies that metacognitive training produces broadly applicable cognitive tools.

Research conducted by Chen et al., (2025), suggests that calibration problems identified in low-achieving students further complicate this picture. These students show excessive self-confidence; this is due to metacognitive calibration errors that can actually hinder learning by reducing strategic effort or help-seeking behavior. The statement suggests that metacognitive teaching cannot be uniform, it must address not only the development of monitoring and regulation skills, but also the accuracy of self-assessment.

The cognitive-affectiveintegration: Beyond dualism

The most theoretically significant finding is the dissolution of the traditional cognitive-affective boundary in metacognitive functioning. This statement is evidenced by the research results of Aydın & Özgeldi (2024), Alzahrani (2022), and Liu et al., (2022), which show that metacognitive emotional operations are functionally inseparable. Math anxiety, for example, not only correlates with metacognitive deficits, but actively interferes with metacognitive monitoring and control processes.

This integration has profound implications for intervention design. Where traditional approaches target metacognitive skills separately from affective factors may be fundamentally misguided. Research conducted by Moustakas & Gonida, (2023), revealed that high-achieving students show diverse motivational-metacognitive profiles. The statement proves that effective metacognitive support is not only cognitively focused, but must also be emotionally intelligent. The mediating role of metacognition between motivation and STEM attitudes further emphasizes that metacognitive development has the same importance in shaping learning identities and dispositions as found in cognitive techniques (Liu et al., 2022). Similarly, the need for differential use of metacognitive components (Henra et al., 2024, 2025) and the influence of cognitive style on metacognitve autonomy (Sutama et al., 2021) underscore the importance of personalized metacognitive instruction that accounts for learner diversity.

Methodological maturation and its discontents

The balanced distribution of qualitative (37.9%), quantitative (34.5%), and mixed methods (27.6%) approaches reflects methodological pluralism, which is a sign of the maturity of the field. However, this diversity masks a more worrying issue, namely the continuing challenge of validly measuring metacognition. Research by Vuorre & Metcalfe (2022), revealed how metacognitive resolution metrics can be affected by guessing behavior in multiple-choice tasks. Meanwhile, research by Hawrot et al., (2025), found that common theoretical assumptions regarding metacognitive accuracy do not hold empirically.

The methodological critique suggests that much of what is thought to be known about metacognition may be a measurement artifact rather than an actual phenomenon. The field's reliance on self-report instruments and confidence assessments may systematically overestimate or misrepresent actual metacognitive functioning. Qualitative research conducted by Altinay & Ünver (2024), Garcia-Moya et al., (2024), and Baumanns & Rott (2023), offers a correction by capturing metacognitive processes directly through problem solving, revealing the dynamic and context-dependent nature of metacognitive regulation that is not represented by quantitative data. However, these studies face limitations in terms of generalizability and replicability.

The technology question: Promise and absence

One of the findings of the VOSviewer analysis is the relative paucity of technology-related research, despite the widespread rhetoric around digital transformation in education. Although research conducted by Wang et al., (2022), and Garcia-Moya et al., (2024), suggests that technology can support metacognitive development, these are isolated examples and do not constitute systematically programmed research. This gap may reflect a disciplinary divide, where educational technology research and metacognitive research operate in parallel rather than in dialog. It also suggests that technology integration in mathematics education has not yet reached the point where metacognitive support becomes a design priority.

Limitations and future directions

This SLR has several limitations, namely: (1) the restriction to English-language publications may exclude important research published in other languages, especially given the geographical concentration in non-English speaking countries; (2) the five-year time span, while capturing recent trends, inevitably misses long-term patterns of conceptual evolution; (3) the 2025 data represent only articles formally published or available as early access at the time of the database search, and the full-year output for 2025 will likely be larger as publication pipelines mature-this is explicitly acknowledged as a limitation of the study; (4) this study focused only on journal articles, excluding grey literature, dissertations, and conference proceedings that may contain emerging ideas not yet formalized in peer-reviewed publications; (5) This study did not employ supplementary search methods such as hand-searching reference lists of included studies or forward citation chasing, which may have resulted in the omission of relevant studies not indexed in the six selected databases.

Future research is expected to prioritize three directions, namely: (1) Longitudinal studies that can track metacognitive development over a long period of time; (2) Test instruments that truly measure levels of metacognitive ability, and not just procedural aspects; (3) Intervention studies that systematically vary instructional components to identify the active ingredients of effective metacognitive instruction.

Conclusion

A systematic review of 29 studies spanning January 2021 to December 2025 (with 2025 data acknowledged as potentially incomplete due to publication lag at the time of the search) revealed that metacognitive research in mathematics education has evolved from conceptual exploration to intervention-focused inquiry, with Turkey and Indonesia leading the productivity (14% each) driven by assessment pressures and curriculum reform. Methodological approaches remain balanced across qualitative, quantitative and mixed methods, although concerns regarding measurement validity remain. Beyond that, metacognitive awareness significantly predicts math achievement in an integrated cognitive-affective system, but transferability between domains remains limited and low-achieving students show systematic calibration failures.

Although interventions suggest that skills are trainable, the field requires longitudinal studies, development of assessment tests, and integration of technology to address knowledge gaps. The transition from theoretical to empirical validation places metacognition at the center of mathematics learning, which demands a pedagogically actionable framework that accounts for individual differences, emotional dimensions, and context-specific constraints in fostering true metacognitive competence.

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References

Almeida, L. M. W. de, & Castro, E. M. V. de. (2023). Metacognitive Strategies in Mathematical Modelling Activities: Structuring an Identification Instrument Estrategias Metacognitivas en Actividades de Modelación Matemática: Estructuración de un Instrumento de Identificación. *Journal of Research in Mathematics Education*, *12*(3), 210–228. https://doi.org/10.17583/redimat.12926

Altinay, E. V., & Ünver, S. K. (2024). Eighth grade students ' metacognitive regulations in problem-solving processes. *Journal of Pedagogical Sociology and Psychology*, *6*(3), 176–192. https://doi.org/10.33902/jpsp.202431057

Alzahrani, K. S. (2022). "Away from the textbook," metacognitive strategies in mathematics: A qualitative study on saudi students' motivation to learn mathematics. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(1), 1–14. https://doi.org/10.29333/EJMSTE/11507

Arslan, B., & Finn, B. (2023). The effects of personalized nudges on cognitively disengaged student behavior in low-stakes assessments. *Journal of Intelligence*, *11*(11), 1–24. https://doi.org/10.3390/jintelligence11110204

Aydın, U., & Özgeldi, M. (2024). What ' s metacognition got to do with the relationship between test anxiety and mathematics achievement? *European Journal of Psychology of Education*, *39*(3), 2509–2529. https://doi.org/10.1007/s10212-024-00797-7

Baumanns, L., & Rott, B. (2023). Identifying metacognitive behavior in problem-posing development of a framework and a proof of concept. *International Journal of Science and Mathematics Education*, *21*(5), 1381–1406. https://doi.org/10.1007/s10763-022-10297-z

Bulut, A. S. (2021). An empirical investigation of mathematics learning approaches and metacognitive awareness of students. *Participatory Educational Research*, *8*(4), 84–102. https://doi.org/10.17275/PER.21.80.8.4

Chen, S., Green, M., & Hodge, K. N. (2025). Four-to-six-year-olds' developing metacognition and its association with learning outcomes. *Frontiers in Education*, *10*, 1–11. https://doi.org/10.3389/feduc.2025.1653320

Eck, N. J. Van, & Waltman, L. (2023). *VOSviewer manual for VOSviewer version 1.6.20*. Universiteit Leiden. https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.20.pdf

Garcia-Moya, M., Marcos, S., & Fernandez-Cezar, R. (2024). Non-routine mathematical problems and the strategies used by gifted students : A case study. *Journal of Research in Special Educational Needs*, *24*(4), 1175–1189. https://doi.org/10.1111/1471-3802.12695

Grenell, A., Butts, J. R., Levine, S. C., & Fyfe, E. R. (2025). Children's confidence on mathematical equivalence and fraction problems. *Journal of Experimental Child Psychology*, *246*, 1–29. https://doi.org/10.1016/j.jecp.2024.106003

Hawrot, A., Gnambs, T., & Lockl, K. (2025). The accuracy of performance judgements and academic achievement : A two-sample two-wave study of German primary and lower secondary school students. *Learning and Individual Differences*, *122*, 102764. https://doi.org/10.1016/j.lindif.2025.102764

Henra, K., Budayasa, I. . K., Ismail, & Liu, M. (2024). What is the room for guessing in metacognition? Findings in mathematics problem solving based on gender differences. *Perspectives of Science and Education*, *69*(3), 469–482. https://doi.org/10.32744/pse.2024.3.28

Henra, K., Budayasa, I. K., & Ismail. (2025). Exploring metacognitive strategies in feminine female high school students : a qualitative study in statistical problem-solving. *Perspectives of Science and Education*, *1*, 336–348. https://doi.org/10.32744/pse.2025.1.22

Lina, S. I., Johar, R., & Anwar. (2025). The role of mathematics education in shaping sustainable futures : A systematic literature review. *Jurnal Elemen*, *11*(3), 757–782. https://doi.org/10.29408/jel.v11i3.29706

Liu, S.-J., Zhou, S.-N., Xu, S.-R., & Xiao, H. (2022). Exploring effect on primary school students' STEM attitude determined via structural equation modeling. *Journal of Baltic Science Education*, *21*(6), 1052–1068. https://doi.org/10.33225/jbse/22.21.1052

Mongeon, P., & Paul-Hus, A. (2015). The journal coverage of Web of Science and Scopus: a comparative analysis. *Scientometrics*, *106*(1), 213–228. https://doi.org/10.1007/s11192-015-1765-5

Moustakas, D., & Gonida, E. N. (2023). Motivational profiles of high achievers in mathematics: relations with metacognitive processes and achievement emotions. *Education Science*, *13*(10), 970. https://doi.org/10.3390/educsci13100970

Novakova, E. (2024). Metacognitive skills of pupils in primary mathematics education. *Journal of Elementary Education*, *17*(2), 223–239. https://doi.org/10.18690/rei.3274

Page, M. J., Mckenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-wilson, E., Mcdonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, *372*(n71). https://doi.org/10.1136/bmj.n71

Pirrone, C., Corrado, D. Di, Privitera, A., Castellano, S., & Varrasi, S. (2022). Students' mathematics anxiety at distance and in-person learning conditions during covid-19 pandemic: Are there any differences? An exploratory study. *Education Sciences*, *12*(6), 1–11. https://doi.org/10.3390/educsci12060379

Rican, J., Chytry, V., & Medova, J. (2022). Aspects of self-regulated learning and their influence on the mathematics achievement of fifth graders in the context of four di erent proclaimed curricula. *Frontiers in Psychology*, *13*, 1–15. https://doi.org/10.3389/fpsyg.2022.963151

Seferian, D. T., Auman, C. M., & Martinez, J. A. H. (2021). Teaching to self-regulate in mathematics: A quasi-experimental study with low-achieving elementary school students. *Redie: Revista Electronica de Investigacion Educativa*, *23*, 1–13. https://doi.org/10.24320/REDIE.2021.23.02.2945

Subba, B. H., Chanunan, S., & Poonpaiboonpipat, W. (2025). A proposed constructivism-based instructional model to enhance metacognition and mathematical problem-solving skills in Bhutanese grade nine students. *Jurnal on Mathematics Education*, *16*(1), 51–72. https://doi.org/10.22342/jme.v16i1.pp51-72

Suliani, M., Juniati, D., & Lukito, A. (2024). Mathematics belief impact on metacognition in solving geometry: Middle school students. *Journal of Education and Learning*, *18*(2), 286–295. https://doi.org/10.11591/edulearn.v18i2.21110

Sutama, Anif, S., Prayitno, H. J., Narimo, S., Fuadi, D., Sari, D. P., & Adnan, M. (2021). Metacognition of junior high school students in mathematics problem solving based on cognitive style. *Ajue: Asian Journal of University Education*, *17*(1), 134–144. https://doi.org/10.24191/ajue.v17i1.12604

Termaat, A. (2024). How disciplinary detail obscures the metacognitive potential of curriculums. *Curriculum Perspectives*, *44*(3), 319–335. https://doi.org/10.1007/s41297-024-00257-8

Vreeze-Westgeest, M. G. J. de, & Vogelaar, B. (2022). Cognitive training in the domain of mathematics for potentially gifted children in primary school. *Education Sciences*, *12*(2), 1–13. https://doi.org/10.3390/educsci12020127

Vuorre, M., & Metcalfe, J. (2022). Measures of relative metacognitive accuracy are confounded with task performance in tasks that permit guessing. *Metacognition and Learning*, *17*(2), 269–291. https://doi.org/10.1007/s11409-020-09257-1

Wahba, F. A., Tabieh, A. A. S., & Banat, S. Y. (2022). The power of STEAM activities in enhancing the level of metacognitive awareness of mathematics among students at the primary stage. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(11). https://doi.org/10.29333/EJMSTE/12562

Wang, G., Kang, Y., Jiao, Z., Chen, X., Zhen, Y., Zhang, D., & Su, M. (2022). Development and application of intelligent assessment system for metacognition in learning mathematics among junior high school students. *Sustainability*, *14*(10), 1–32. https://doi.org/10.3390/su14106278

Yıldız, K. A., & Öztürk, M. (2023). Relationship between middle school students' metacognition and problem-posing performance: A serial mediation analysis. *Journal of Pedagogical Research*, *7*(5), 324–343. https://doi.org/10.33902/JPR.202323665

Zhang, J., Zhou, Y., Jing, B., Pi, Z., & Ma, H. (2024). Metacognition and mathematical modeling skills: The mediating roles of computational thinking in high school students. *Journal of Intelligence*, *12*(55), 1–18. https://doi.org/10.3390/jintelligence12060055