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Cognitive and Metacognitive Strategies for Learning Algebra: A Mini Review

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ABSTRACT - Algebra learning can be strengthened with a combination of cognitive and metacognitive strategies. This effectiveness is most evident when learning support is arranged sequentially and tailored to students' proficiency and task complexity. However, many students have difficulty understanding symbolic procedures to algebraic concepts that involve abstract structures and relationships. Thus, this mini review aims to synthesize all studies done from 2015 to 2025, which related to the cognitive and metacognitive mechanisms that support algebra learning and also to report the use of cognitive and metacognitive strategies to enhance conceptual understanding, problem-solving and self-regulated learning in algebraic education. The study focuses on several specific themes for learning algebra namely, instructional approaches, metacognitive strategies and cognitive strategies for learning algebra. The databases used for searching literature for this review using keywords included Scopus, ProQuest and Google Scholar regarding strategies in learning Algebra for conceptual understanding and problem-solving. A total of 423 articles for full-text review and 43 were finally selected for this review. The findings of this mini-review reveal the combination of cognitive and metacognitive strategies contribute to stronger knowledge retention, transfer and mathematical resilience. Cognitive strategies can support structured algebraic reasoning and procedural clarity while metacognitive strategies can enhance monitoring, reflection and error correction during completed the task. To this end, this review highlights the transformative potential of innovative learning strategies into algebra curricula. However, the existing evidence base remains limited due to the short intervention period, inconsistent definitions and measurements of metacognition, and inconsistent classroom implementation. Further investigations should expand empirical validation and explore instructional designs more specific and reliable.

INTRODUCTION

In mathematics education, algebra is a key component and many students of all ages have struggled to develop an understanding of algebra. Recent studies have shown that there is a shift from traditional procedure-oriented teaching to cognitive and metacognitive approaches that emphasize how students

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plan, think and reflect during problem solving. Study by Mutawah et al. (2019) found that the students' level of procedural understanding is high whereas the level of conceptual understanding is low. They suggested that a reformation in teaching is needed to boost conceptual understanding among students to minimize the use of procedures and memorization. Effective use of mathematical knowledge, especially in basic areas such as algebra, is important for students' academic progress and broader problem-solving abilities (Contente & Galvao, 2022; Yousef, 2024). In addition, studies on cognitive and metacognitive strategies are increasingly prominent in fostering deep understanding and competence in mathematics learning (Ishak, Oderinde & Ahmad, 2025; Zeitlhofar et al., 2023). Huang, Riccomini dan Morano (2019) found that algebra instruction has merely focused on symbolic manipulations executed through repeated practice while solving abstract equations causing the cognitive process has been fixed and limited to the abstract stage. Cognitive strategies refer to the mental processes that individuals use to acquire, store and retrieve information, including techniques such as practice, elaboration and organization (Zhang & Zhang, 2024). On the other hand, metacognitive strategies involve awareness and regulation of one's own thought processes, including monitoring, planning and evaluating learning activities (Ishak, Oderinde & Ahmad, 2025; Zhang & Hew, 2025; Zhang & Zhang, 2024).

This mini review aims to synthesize all studies done (2015 to 2025) in understanding the cognitive and metacognitive mechanisms that support algebra learning. In addition, the use of cognitive and metacognitive strategies to enhance conceptual understanding, problem-solving and self-regulated learning in algebraic education are reported. The study focuses on several specific themes namely, instructional approaches, metacognitive strategies and cognitive strategies for learning algebra. This mini-study also addresses specific knowledge gaps regarding their implementation and effectiveness across a variety of educational contexts and student profiles. Therefore, the primary purpose of this mini-study is to examine the effectiveness of explicitly teaching metacognitive strategies and the complex relationship between cognitive skills and student engagement in improving problem-solving skills and complex mathematical assignments.

Cognitive and metacognitive strategy approaches can promote knowledge construction beyond rote learning to deeper conceptual understanding (Anthonysamy et al., 2024; Yang et al., 2024; Remillard & Kim, 2020). According to Anthonysamy et al. (2024), the fundamental to improving analytical thinking skills is through metacognitive knowledge, which includes understanding one’s own learning strengths and weaknesses, task demands and strategy application. In addition, metacognitive regulation is essential for effectively managing cognitive processes such as planning, monitoring and control (Anthonysamy et al., 2024; Lu, Limniou & Zhang, 2024). The challenge remains in consistently implementing into pedagogical designs that are practical and effective meeting the unique needs of all students in algebra education (Machalow et al., 2020; Brouwer et al., 2022). Furthermore, this cognitive component is fundamental to the acquisition of algebraic understanding. Fagerholm et al. (2022) described perception, attention, memory, learning, cognition, reasoning, problem solving, cognitive biases and knowledge as the main cognitive aspects related to learning. Metacognitive strategies discussed are intended to supervise and guide these cognitive processes to ensure their efficient application in problem-solving scenarios.

The main conclusion drawn from this synthesis highlights the great potential of integrated instructional approaches that incorporate cognitive and metacognitive strategies to enhance algebra learning outcomes. Instructional approaches need to be more comprehension-centered, relate algebra to real-world applications, provide adequate practice and leverage technology and collaborative learning to enhance student mastery (Alias et al., 2025). Current research demonstrates how cognitive and metacognitive processes specifically support algebraic reasoning remains fragmented and inconclusive despite their recognized importance in mathematics learning. Other studies have found metacognitive training has limited impact when not accompanied by adequate cognitive scaffolding or practical teacher guidance (Budin, Patti & Rafferty, 2022). Teachers encourage students to become more independent and effective learners by teaching them how to plan, monitor and assess their own learning processes (Anthonysamy et al., 2024). This can result in better academic performance. Therefore, the debate continues among researchers as to whether metacognitive skills require explicit, intentionally designed instruction or develop naturally as a result of mathematics learning experiences.

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METHODOLOGY

We conducted a search was made on the Scopus, ProQuest and Google Scholar databases to ensure comprehensive coverage of the topic. We focused on publications that seek to clarify the strategy of teaching or learning algebra in mathematics education. Among these, Scopus indexes covers over 6027 active journals, ProQuest covers over 510 journals and Google Scholar limited to the first 100 articles. A total 423 articles have been identified and 43 articles were finally selected in this review. The search string in Scopus was as follows: ("cognitive" OR "metacognitive" OR "thinking" OR "awareness") AND ("strategies" OR "approaches" OR "techniques" OR "methods") AND ("algebra" OR "mathematics" OR "math" OR "arithmetic") AND ("learning" OR "education" OR "instruction" OR "teaching") AND ("problem solving" OR "critical thinking" OR "conceptual understanding" OR "skills"). These keywords were used such as cognitive; metacognitive; learning strategies; algebra; conceptual understanding to collect relevant articles. Additionally, the search was limited to articles published in the past ten years, from 2015 to 2025. This inclusion and exclusion criteria for studies in this review article are provided as in the following.

Inclusion criteria

- Studies that discussed key aspects of cognitive and metacognitive strategies and their implementation in the context of algebra education.
- Studies that analyzed cognitive and metacognitive teaching strategies in improving students' conceptual understanding and transfer of algebraic knowledge in terms of strengths, limitations and potential applications.
- English-language articles were considered.

In learning algebra, the reviewed studies showed that cognitive and metacognitive strategies are complementary role in fostering conceptual understanding and flexible problem-solving. Based on these findings, these strategies suggest that instruction is more effective when it able to help students become more self-aware and reflective about their own learning processes.

Exclusion criteria

- Studies published in languages other than English were excluded.
- Studies that discussed mathematics education or learning processes without explicit references to cognitive or metacognitive strategies in the context of algebra were excluded.
- Gray literature, including conference abstracts, unpublished theses, dissertations, and reports, were excluded.

Several exclusion criteria were used with a thorough literature search and multi-stage selection process to ensure data credibility. Research that lacks a clear analytical focus on the targeted concept, such as studies only emphasize affective or motivational factors without addressing strategy use were also excluded. This approach aims to maintain the credibility, reliability and scholarly integrity of the review findings.

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DISCUSSION AND RESULT

An overview of how cognitive, metacognitive and instructional approaches interrelated to support algebra learning is shown in Figure 1.

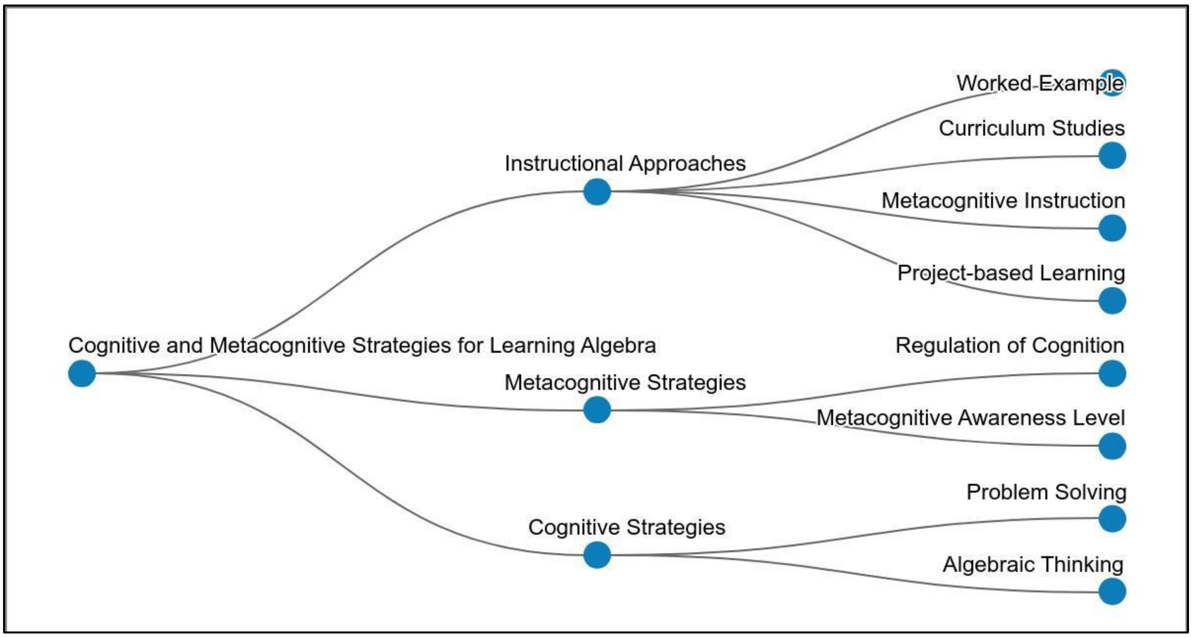

Figure 1. Cognitive and Metacognitive Strategies for Learning Algebra (Generated by Scopus AI)

A mini-review based on the theme Instructional Approaches

The main factor that makes students weak in basic algebra is a teaching approach that does not focus on understanding concepts (Alias et al., 2025). Students who like to memorize solution steps without understanding the concepts algebra problems will face difficulties when faced with more complex problems. Algebra learning can be improved when using instructional approaches that incorporate cognitive and metacognitive strategies. Cognitive learning strategies refer to techniques and approaches that learners use to process information, such as summarizing, note-taking, elaboration, worked examples, schema induction and analogy reasoning (Jiang et al., 2023; Durkin et al., 2021; Anthonysamy et al., 2024). In contrast, metacognitive learning strategies involve learners' awareness and control of their own cognitive process information, such as goal setting, monitoring, evaluating their own learning and strategy adjustment (Broadbent & Poon, 2015). Many high school students find algebra difficult because it requires understanding abstract concepts, manipulating symbols and signs, and solving multi-step problems (Bhatia & Chakraborty, 2024). Recent studies have successfully proven that metacognition is an important practice in students' long-term academic performance. This implication automatically supports a pedagogical approach that integrates metacognitive development into instructional design (He et al., 2024).

According to Zeitlhofer et al. (2023), there is a discrepancy regarding the metacognitive effects of immediate tasks. New students feel burdened by explicit metacognitive instruction in terms of cognitive load. The discussion continues with the optimal sequence between cognitive and metacognitive strategies, namely which strategy should precede, alternate or be used after students have achieved basic cognitive skills. Besides that, the implementation of teacher loyalty and the feasibility of interventions remain inconsistent. Study by Alias et al. (2025) showed that the use of technology, collaborative learning, contextual approaches and structured exercises were able to improve students' understanding of algebra learning. Interactive approaches such as the use of mathematical software and applications in everyday life played an important role in strengthening the foundations of algebra in addition to focused guidance and the provision of structured exercises.

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Therefore, classroom-scale studies examining learning durability, transfer to new problem forms and the impact on fairness in long term education still lacking. Comparisons across studies are difficult because of the wide variety of metacognitive measurement methods. Future research includes conducting research on optimal teaching sequences tailored to students' skill levels, implementing multi-site longitudinal studies, developing validated, shared measures of metacognitive processes. In conclusion, algebra learning comprehension is expected to be enhanced if the interaction between cognitive strategy instruction and metacognitive regulation consistently made, thereby shaping cognitive flexibility and knowledge transfer abilities, especially when supports are appropriately tailored and aligned with instructional objectives. The field still needs robust and standardized metacognitive measures, teacher-centered implementation and transparent adaptive models. Hence, progress in this area has the potential to transform small-scale successes into sustainable, widespread and equitable algebra teaching practices for all students.

A mini-review based on the theme Metacognitive Strategies.

Metacognition is the ability of a person to manage things and control the way to thinks. Metacognitive strategies involve students' awareness, control and self-regulation of their own thinking processes in education systems (Sun, 2024; Bingham et al., 2021; Anthonysamy et al., 2020; Crasta & Coutinho, 2024). This strategy is increasingly recognized as a pillar of effective algebra learning because it requires understanding abstract concepts, manipulating symbols and signs, and problem-solving processes (Bhatia et al., 2024). In recent decades, educational research has shifted away from the mastery of cognitive skills alone to an emphasis on metacognition as a catalyst for self-directed learning. Self-efficacy, from the educational context, is a student's self-confidence to perform certain academic tasks smoothly. It is very important because it can influence an individual's choices in effort, perseverance and feelings (Chan, 2025). There are empirical studies that state that self-efficacy has a significant relationship with cognitive constructs such as academic achievement (Recber et al., 2017; Ugwuanyi, 2020). A correlation analysis study by Tian, Fang dan Li (2018) found that there is a positive relationship between self-efficacy and student metacognition engagement. Therefore, teaching metacognitive strategies appears to be a relevant and practical approach to improving individual learning outcomes and overall educational equity.

Cognitive development aspects of reasoning skills can influence students' metacognition towards mathematical understanding (Lestari & Jailani, 2018). Empirical studies have also shown that the influence of metacognition can develop students' thinking (Lee et al., 2018; Lestari & Jailani, 2018). With awareness of metacognitive knowledge and self-regulation, students are able to use appropriate learning strategies to achieve their learning goals (Haryani et al., 2018). The component of metacognitive knowledge allows a student to learn how, when and where they can use their cognitive strategies (Young & Worrell, 2018). Metacognition awareness can influence a student's success, including in accessing and activating existing knowledge, organizing information, knowing how and when to use specific learning strategies, controlling the effectiveness of learning strategies and applying what has been learned (Chan, 2025).

However, there is still debate among scholars about metacognition strategies are usually not specifically taught in teaching and learning (Roick & Ringeisen, 2018). For example, a study by Akben (2020) further explained students' mathematics problem-solving strategies, without explaining in detail the dimensions of metacognitive awareness that can influence students' mathematics problem-solving strategies. The implication is that a lack of metacognitive awareness in student learning can negatively affect students' academic performance, especially in mathematics (Abdelrahman, 2020). Researchers found that most previous studies have focused on metacognitive awareness on mathematics achievement (Kartika & Firmansyah, 2019; Smith & Mancy, 2018; Young & Worrell, 2018) and related studies have found that the contribution of metacognitive awareness to mathematical reasoning is small.

Metacognitive strategies are an important foundation for algebra learning because they link cognitive skill mastery with self-reflective learning. Empirical evidence consistently shows that these strategies enhance students' conceptual understanding, mathematical reasoning, and autonomy in regulating the learning process, which are considered important in students' skill sets. This field still faces methodological and implementation challenges. Among them is the lack of standardized measures and metacognitive and directed teacher training. Future directions for research and practice should focus on developing an evidence-based integrated framework that combines cognitive and metacognitive

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support. It empowers teachers to guide students to become reflective and independent thinkers, in line with the complex reasoning demands of the 21st century.

A mini-review based on the theme Cognitive Strategies.

Cognitive strategies refer to the methods students to identify, acquire and process new information and to integrate it in established knowledge structures. In terms of students' mathematical reasoning, there are studies found that cognitive style and learning reasoning skills are interrelated. The three cognitive activities involved in learning mathematics are exploration or investigation, problem solving and proof (Thuneberg et al., 2018). As detailed by Bayat dan Meamer (2016), strategies are divided into two, namely surface cognitive strategies and deep cognitive strategies. Surface cognitive strategies involve the repetitive rehearsal and rote memorization of information, which help to encode new information into short-term memory, mainly through reading the course material over and over again. On the other hand, deep cognitive strategies refer to elaborating, organizing and critical thinking, and they challenge the reality of information encountered and attempting to integrate new information with past knowledge and experience, which facilitate long-term retention of the target information, for example making an outline of important concepts after a learning session (Bayat & Meamar, 2016).

Recent studies have shown that combining strategies such as worked-example study, self-explanation, and example fading can accelerate initial learning and reduce student errors. Strategies such as structure mapping and multiple solution comparison have been found to strengthen students' ability to generalize mathematical concepts and think flexibly (Costley et al., 2023). Nevertheless, some issues are still debated among researchers regarding the most effective teaching sequencing, whether students need to see examples first or try their own solutions before receiving examples (example-first vs. problem-first), and the more appropriate form of practice, such as blocked practice or interleaved practice. Additionally, there is the question of which students should engage in productive struggle before receiving intervention guidance. From an implementation perspective, the issue of teacher fidelity to the designed strategies and adapting them to actual classroom timetables poses additional challenges. Teachers often report difficulties in balancing between strategies and the needs of dense curriculum content (Alvarado & Galigao, 2024).

Most existing research is still limited to short-term intervention periods and conducted in controlled environments. Long-term evidence on the durability of learning, transfer to new forms of algebra, and the impact on justice learning among students of varying ability levels is still lacking. Therefore, future research should involve long-term studies of various forms to determine when and how cognitive support should be reduced (fading supports). Additionally, it can identify schedules that are adaptive based on student skill levels for interleaving and spaced retrieval strategies. There is also a need to combine cognitive routines with metacognitive review brief (micro-reflection prompts) to maintain long-term effects. In addition, learning analytics, and interactive authoring tools have expanded the potential for implementing cognitive and adaptive strategies. However, there are still constraints related to the transparency of adaptive systems, the balance between automation and autonomy for students, and the ethics of using learning data. Overall, cognitive strategies are effective in enhancing algebra learning by reducing cognitive load, fostering a deep structural understanding, and improving knowledge transfer capabilities (Costley et al., 2023). Therefore, incorporating robust of cognitive strategies with metacognitive can provides a practical path towards sustainable, flexible, and deep-understanding algebra learning.

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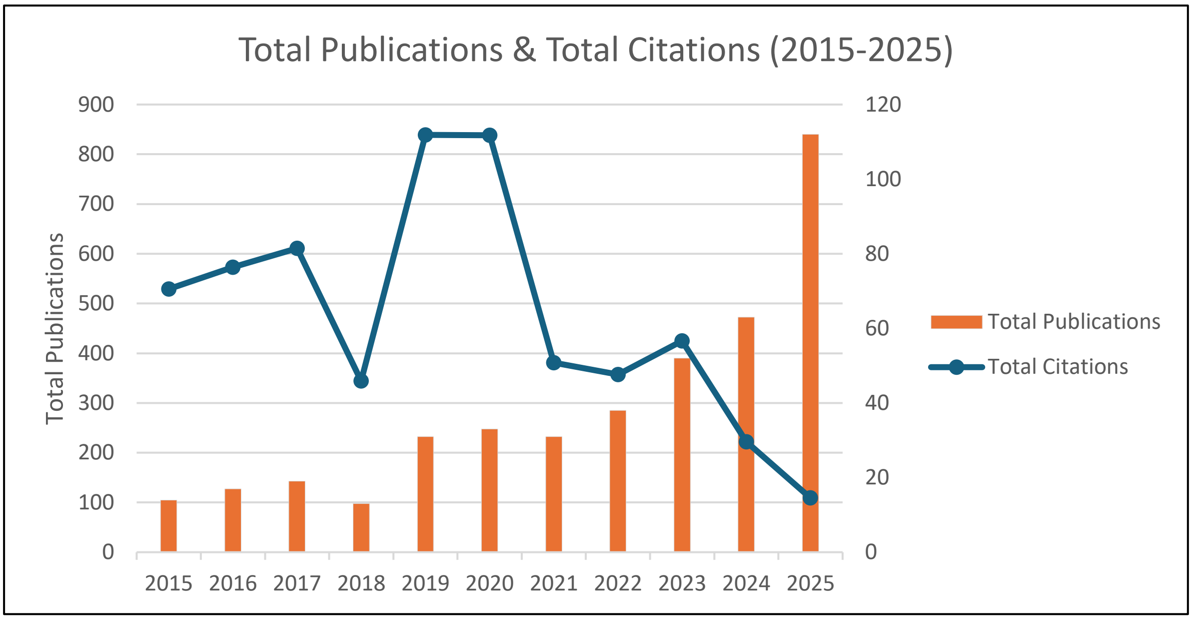

Figure 2. Total Publications and Total Citations from 2015 until 2025

Based on publication data from 2015 to 2025, research in the field of cognitive and metacognitive strategies rising from 2015 to the highest levels in 2024 and 2025. This reflects the rapidly growing interest of this field of study. However, around 2019 to 2020, the number of citations peaked earlier before declining significantly between 2021 and 2025. This phenomenon illustrates the occurrence of citation lag, which is a situation where recent publications has not yet generated equivalent citations. Overall, these patterns indicate that the rapid increase in the number of publications at the end of the period. It shows that it does not necessarily reflect an immediate impact as citation effects usually emerge several years later.

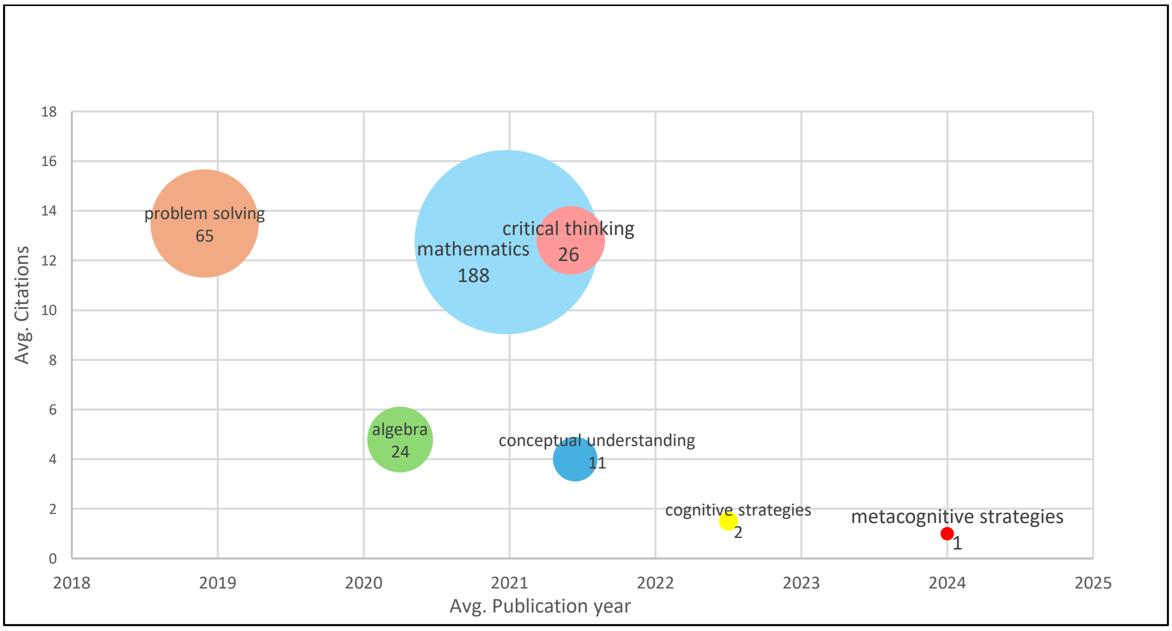

Figure 3. Average Publication Year vs Average Citations

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These findings show a rapid increase in publications related to cognitive and metacognitive strategies after 2015, indicating a rapid growth in researchers' interest in strategy-based learning in mathematics education. Based on keyword analysis, the highest average citations in the dataset are in the theme algebra and conceptual understanding have strong research base. Aligning with current learning needs, trends indicate an increase in studies focusing on thinking strategies and self-regulation. The keywords 'cognitive strategies' and 'metacognitive strategies' show a newer average year of publication which proves that this field is actively developing and still attracting the attention of the global research community. However, the lower average citations for these new themes may be due to citation lag. This suggests a high potential for future impact growth as more empirical studies are conducted and referenced. Current studies approach that the importance and relevance of this mini-review to strengthen students' conceptual understanding, problem-solving skills and cognitive resilience in the context of modern mathematics education.

CONCLUSION

Based on various recent studies, algebra learning can be strengthened with a combination of cognitive and metacognitive strategies. The findings focused only to three themes namely instructional approaches, metacognitive strategies and cognitive strategies for learning algebra. This effectiveness is most evident when learning support is arranged sequentially and tailored to students' proficiency and task complexity. Academic institutions, administrations and educators can work together to create teaching and learning strategies that combine cognitive and metacognitive aspects that are more structured, flexible and easy to use in improving algebra mastery. However, the existing evidence base remains limited due to the short intervention period, inconsistent definitions and measurements of metacognition, and inconsistent classroom implementation. Debates also continue regarding the best time and methods for introducing self-regulation strategies, the optimal level of guidance versus productive struggle, and the balance between adaptive system automation and the roles of student and teacher agency in technology-enhanced learning environments. Key gaps identified include a lack of long-term, multi-site evidence on learning resilience and equity, a lack of process measures and standard rubrics for metacognitive quality, and a lack of validated trigger thresholds for adaptive prompts and instructional designs tailored to student diversity and the digital learning context. Therefore, future research is recommended to prioritize long-term, mixed-methods design-based studies, the development of shared measurement frameworks, and the packaging of high-impact, small-scale classroom routines, such as brief self-explanation and plan-solve-check cycles, supported by targeted professional development for teachers.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTION

(Izan Roziana Mohd Dadiri): Writing- Original draft preparation, Data curation. **(Rohaidah Masri)**: Conceptualization, Original draft preparation, Editing. **(Mazlini Adnan)**: Review, Editing. **(Mohd Syazwan Mohd Roslan)**: Visualisation, Review.

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DECLARATION OF GENERATIVE AI

During the preparation of this manuscript, the researchers used OpenAI ChatGPT solely for language editing and improving the clarity of the writing. The researchers used Scopus AI to find key themes related to the title. No generative artificial intelligence tools were used to generate or interpret any scientific content. The authors carefully reviewed and revised the text as required and are solely responsible for the final content of this publication.

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