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Research trends in mathematical literacy and self-regulated learning: A scoping review using bibliometric analysis

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Abstract
Mathematical literacy and self-regulated learning (SRL) are essential competencies for students' success in mathematics. However, research on their intersection remains fragmented, lacking a comprehensive overview of trends, key themes, and influential contributions. This study used Google Scholar and Publish or Perish to conduct a scoping review and bibliometric analysis of mathematical literacy and SRL research from 2009 to 2023. The analysis included publication trends, citation patterns, co-word analysis, and collaboration networks. The findings showed a significant increase in research after 2015, with peaks in publications in 2021 and 2022. Key themes include cognitive strategies, motivation, pedagogical approaches, technological integration, and assessment methods. The most cited works emphasize SRL's role in problem-solving, metacognition, and technology-enhanced learning. Collaboration networks indicate that research is dominated by North American, European, and Australian institutions, with limited contributions from developing regions. The study suggests expanding AI-enabled SRL research, teacher professional development, and culturally diverse frameworks to enhance mathematical literacy instruction globally. These insights contribute to advancing evidence-based instructional models that integrate Technology, self-regulation, and mathematical reasoning to improve learning outcomes.

Keywords: bibliometric analysis; mathematical literacy; metacognition; self-regulated learning; technology-enhanced learning

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I. Introduction

In mathematics education, mathematical literacy and self-regulated learning (SRL) play critical roles in shaping students' ability to understand, apply, and communicate mathematical concepts effectively. Mathematical literacy is not just about computational proficiency; it encompasses problem-solving, reasoning, and the ability to interpret mathematical information in real-world contexts (Chen et al., 2022; Muliawanti & Badu Kusuma, 2021). Similarly, self-regulated learning (SRL) enables students to manage their learning processes, set goals, monitor progress, and employ effective strategies to solve mathematical problems (Boekaerts, 1999; Panadero, 2017). These constructs contribute to students' ability to engage in meaningful mathematical thinking and

learning, fostering independence and resilience in academic pursuits (Moala & Hunter, 2019).

Despite their importance, students often struggle with mathematical literacy and self-regulation, leading to difficulties in problem-solving, conceptual understanding, and mathematical reasoning (OECD, 2023). Research has identified several challenges in these areas, including students' inability to reflect on their learning, poor metacognitive regulation, and difficulties applying mathematical knowledge to unfamiliar contexts (Özcan, 2016). Furthermore, many students lack motivation and effective self-regulatory strategies, negatively impacting their mathematical performance (El-Adl & Alkharusi, 2020; Gabriel, Buckley & Barthakur, 2020). This highlights the need for educational interventions that promote mathematical literacy and self-regulated learning strategies to support students in developing higher-order thinking skills (Kramarski & Mizrachi, 2006).

While extensive research has been conducted on mathematical literacy and SRL, there remains a gap in comprehensive reviews that systematically analyze trends in this area. Most existing studies have focused on individual aspects of mathematical literacy or SRL, but few have explored their intersection using a systematic and quantitative approach (Cheung, 2017; Losenno, Muis, Munzar, Denton, & Perry, 2020). A scoping review combined with bibliometric analysis is crucial to map the research landscape, identify key themes, and highlight influential works in this field. Scoping reviews broadly examine literature, capturing major research directions, theoretical frameworks, and emerging trends (Panadero, 2017). Meanwhile, bibliometric analysis offers a quantitative perspective, analyzing publication trends, citation patterns, and academic impact within the domain (Donthu, Kumar, Mukherjee, Pandey & Lim, 2021).

To address this gap, this study conducts a scoping review using bibliometric analysis to examine research trends in mathematical literacy and self-regulated learning from 2009 to 2023. The period from 2009 to 2023 was chosen for several reasons. First, 2009 marks the early emergence of integrated studies linking mathematical literacy with self-regulated learning in international academic databases. Second, during this period, significant educational reforms and global assessments (such as PISA 2009, 2012, 2015, and 2018) increasingly emphasized mathematical literacy and student self-regulation. Third, bibliometric tools require a sufficiently long time to identify meaningful publication patterns, emerging themes, and citation networks. By including publications up to 2023, this review also ensures that the most current trends are captured for relevance to future research and policy. By employing bibliometric methods, we aim to:

1. Identify the most influential studies, authors, institutions, and sources in mathematical literacy and SRL research.
2. Analyze publication and citation trends over the past decade to determine shifts in research focus.
3. Conduct co-word and co-authorship analysis to explore thematic developments and academic collaboration networks.

Previous reviews in this field have primarily focused on theoretical models, pedagogical strategies, or specific instructional interventions (Buchbinder & McCrone, 2022; Kramarski, 2012). However, they lack a bibliometric dimension that systematically maps the evolution of research in mathematical literacy and SRL. This study fills that gap by providing a quantitative synthesis of research activity, highlighting key patterns and emerging topics within the literature.

This study offers a comprehensive overview of research trends in mathematical literacy and SRL, focusing on identifying dominant themes, influential publications, and areas needing further exploration. By doing so, this review aims to contribute to the broader mathematics education research community by guiding future studies and informing instructional

practices. The following research questions guide this scoping review using bibliometric analysis:

1. What are the publication and citation trends in mathematical literacy and self-regulated learning between 2009 and 2023?
2. Which documents, authors, institutions, and countries are the most productive and influential in this research area?
3. What are the most commonly appearing keywords associated with mathematical literacy and SRL, and how have these keywords evolved?
4. What are the patterns of academic collaboration among researchers and institutions in mathematical literacy and SRL research?

By addressing these questions, this study provides a structured and data-driven perspective on the current state of mathematical literacy and self-regulated learning research, offering valuable insights for educators, researchers, and policymakers.

II. Research Method

This study conducts a scoping review and bibliometric analysis to comprehensively overview research trends in mathematical literacy and self-regulated learning (SRL) (Aria & Cuccurullo, 2017; Donthu et al., 2021). The scoping review follows the framework outlined by (Arksey and O'Malley, 2005) and the Joanna Briggs Institute (JBI) guidelines (Tricco et al., 2018) to systematically identify, analyze, and map relevant studies. Meanwhile, bibliometric analysis allows for a quantitative examination of publication trends, citation impact, keyword co-occurrence, and collaboration networks (Fuad, Suyanto, Sumarno, Muhammad & Suparman, 2022; Suyanto, Fuad, Antrakusuma, Suparman & Shidiq, 2023). This study follows five key stages of bibliometric analysis, as illustrated in Figure 1, which provides a structured approach to mapping research activity in this field.

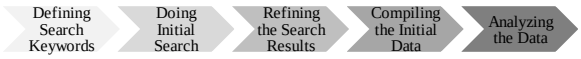

Figure 1. Stages of bibliometric analysis

Defining Search Keywords

A systematic search was conducted using Google Scholar and Publish or Perish, two widely recognized databases for academic research in education and mathematics, to identify relevant documents on mathematical literacy and self-regulated learning. The search was performed in January 2024, utilizing various keyword combinations to ensure comprehensive coverage of related studies. The search terms used included "mathematical literacy" AND "self-regulated learning," "mathematical literacy" AND "metacognition," "self-regulation in mathematics education," and "cognitive strategies in mathematical literacy." Boolean operators (AND, OR) were employed to refine the search results, ensuring the inclusion of relevant studies addressing both mathematical literacy and self-regulated learning.

Doing Initial Search

The initial search retrieved 350 documents published between 2009 and 2023, including peer-reviewed journal articles, conference proceedings, book chapters, and review papers. These documents offered a broad range of insights into research trends and methodologies. The studies varied in language, research design, and publication source. However, to ensure consistency and accessibility, only English-language publications were considered for further analysis.

Refining Search Results

Inclusion and exclusion criteria were applied to ensure that only the most relevant studies were included. Studies were deemed eligible if published between 2009 and 2023, appeared in indexed peer-reviewed journals, and specifically focused on mathematics education. Additionally, selected studies had to be written in English and explicitly address self-regulated learning and mathematical literacy. Studies that did not meet these criteria—such as non-peer-reviewed sources, research outside the field of mathematics education, and publications in non-English languages—were excluded. The

systematic selection process adhered to the four PRISMA stages: Identification, Screening, Eligibility, and Inclusion, resulting in a final selection of 30 studies for in-depth analysis. The document selection process is illustrated in Figure 2, which presents a clear overview of how the studies were filtered.

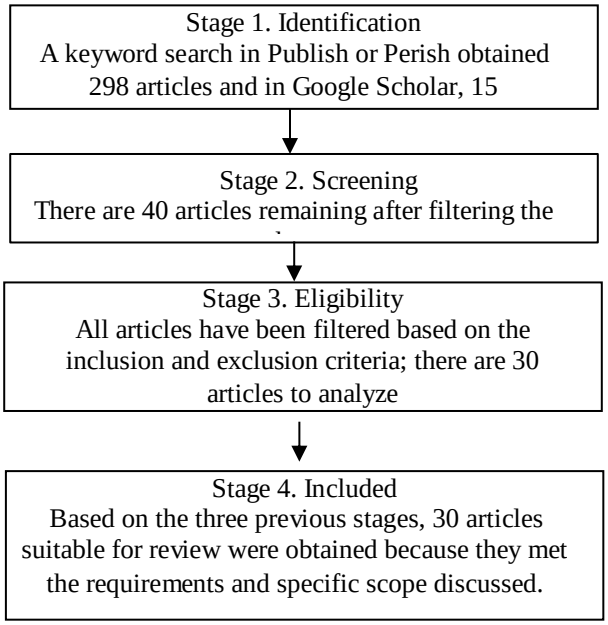

Figure 2. PRISMA stages

Compiling Initial Data

Once the relevant studies were identified, the documents were downloaded in CSV and RIS formats to facilitate bibliometric analysis. The collected data included bibliographic details such as title, author(s), publication year, journal name, citation counts, and journal impact factors. Additionally, abstracts and keywords were extracted to support thematic and keyword-based analyses. To ensure a structured organization of data, Publish or Perish (PoP) software was used for bibliometric processing, allowing for the extraction of key indicators such as Total Citations (TC), Total Publications (TP), Authors per Publication (NAP), Citations per Publication (NCP), Citations per Year (NCY), and h-index values (Fuad et al., 2022).

Analyzing the Data

The selected studies were analyzed using performance analysis, citation analysis, co-word analysis, and co-authorship analysis to examine research trends in mathematical literacy and self-regulated learning comprehensively. Performance analysis was conducted to explore publication trends and citation patterns from 2009 to 2023, identifying key developments, influential studies, and major publication years. This analysis provided insights into the growth of research interest in mathematical literacy and SRL over time.

Citation analysis was employed to understand the research landscape further and identify the most influential documents, authors, institutions, and sources in the field. By tracking citation growth over time, this analysis offered insights into key publications' impact and academic reach. Meanwhile, co-word analysis was performed to explore the research's thematic relationships and keyword co-occurrences. This involved mapping frequently appearing keywords and their connections, allowing for the identification of emerging topics and underexplored areas in mathematical literacy and SRL research.

Additionally, co-authorship analysis was conducted to examine collaboration patterns among researchers and institutions. This analysis revealed dominant research clusters, global academic networks, and potential interdisciplinary collaborations. To enhance visualization, VOS viewer software was used to generate network maps illustrating keyword co-occurrence, overlay visualizations of research trends, and hierarchical clustering of major research themes. This approach facilitated a more precise representation of thematic structures and academic relationships in mathematical literacy and self-regulated learning research.

III. Results and Discussion

Result

1. Trends in Publication and Citation in Mathematical Literacy and SRL (2009–2023)

This section presents the scoping review findings and bibliometric analysis on mathematical literacy and self-regulated learning (SRL). The results are structured to address the research questions, focusing on publication and

citation trends, influential studies, thematic developments, and collaborative research networks. Each subsection provides an in-depth analysis supported by relevant references.

The analysis of publication trends in mathematical literacy and self-regulated learning from 2009 to 2023 reveals a fluctuating yet increasing research interest in this field. Figure 3 illustrates the number of publications per year, indicating that research output has increased significantly in the last decade, with peak years occurring in 2021 and 2022. This aligns with broader trends in education research emphasizing self-regulation and metacognition as key competencies for 21st-century learning (Panadero, 2017).

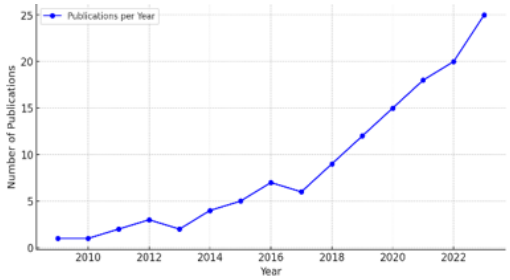

Figure 3. Trends in mathematical literacy and SRL publications (2019-2023)

Although the early 2010s showed limited research output, the field experienced a notable rise post-2015, driven by an increasing focus on student-centered learning, problem-solving, and metacognitive regulation (Boekaerts & Niemivirta, 2000; Gabriel et al., 2020). By 2021, research output peaked, with studies linking self-regulated learning strategies to mathematical performance and literacy development (Harding et al., 2019). This growth can be attributed to global shifts toward competency-based education and the integration of digital learning tools, which support SRL in mathematics education (Wang & Sperling, 2020).

Regarding citations, Figure 4 shows that the most-cited articles were published between 2012 and 2018, indicating that foundational mathematical literacy and self-regulated learning studies have had long-term academic impact. Notably, research by Kramarski & Mizrachi (2006; Moos & Ringdal, 2012) is among the most frequently cited works, highlighting the importance of self-regulated learning interventions in improving mathematical reasoning and literacy.

Figure 4. Citation trends in mathematical literacy and SRL research (2019-2023)

Despite the increase in publications, citation trends show variability, suggesting that not all published studies significantly influence the field. This reinforces the need for further theoretical consolidation and cross-disciplinary engagement to strengthen the research base (Losenno et al., 2020; Wang & Sperling, 2020).

2. Most Influential Documents, Authors, Institutions, and Countries

1. Most-Cited Documents and Key Contributions

Table 1 presents the top five most-cited documents in mathematical literacy and SRL. These studies have significantly shaped research directions and informed instructional practices.

Table 1. Top five most-cited studies in mathematical literacy and SRL

Authors	Title	Year Cite	Key Contributions
(Boekaerts & Niemivirta, 2000)	Self-regulated learning: Where we are today	2016 445	Conceptual framework for SRL in mathematics
(Gabriel et al., 2020)	The impact of mathematics anxiety on SRL and literacy	2020 227	Relationship between math anxiety and SRL
(Moos & Ringdal, 2012)	Self-Regulated Learning in the Classroom: A Literature Review	2012 165	Review of teacher roles in SRL

(Özcan, 2016)	The relationship between mathematical problem-solving skills and SRL	2016 150	Role of SRL in problem-solving
(Wang & Sperling, 2020)	Characteristics of Effective SRL Interventions in Mathematics	2020 128	Effective instructional designs for SRL

The most influential studies have focused on conceptualizing self-regulation in mathematics education, investigating its link to problem-solving, and exploring the role of instructional strategies in promoting mathematical literacy (Boekaerts & Niemivirta, 2000; Gabriel et al., 2020; Özcan, 2016).

2. Leading Authors and Institutions

Table 2 presents the top five most productive authors and institutions in mathematical literacy and self-regulated learning research.

Table 2. Leading authors and institutions in mathematical literacy and SRL research

Author	Institution	Publications	Citations
Boekaerts, M.	University of Leuven	5	445
Moos, D. C.	Wake Forest University	4	165
Gabriel, F.	Australian Catholic University	3	227
Wang, Y.	University of Maryland	3	128
Özcan, Z.Ç.	Turkey	3	150

Research on mathematical literacy and SRL has been dominated by institutions in the United States, Australia, and Europe, reflecting global priorities in education reform. The influence of European research centers, particularly in Belgium and Turkey, highlights their contributions to self-regulation and metacognitive studies in mathematics education.

3. Thematic Analysis of Mathematical Literacy and SRL Research

Co-Word Analysis: Dominant Themes in Research. A co-word analysis was conducted to identify frequent and emerging themes in mathematical literacy and SRL research. Figure 5 presents the most commonly occurring keywords and thematic clusters. Key research themes include:

- Mathematical problem-solving and SRL (Özcan, 2016; Wang & Sperling, 2020).
- Cognitive and metacognitive strategies in mathematics (Kramarski & Mizrachi, 2006).
- Technology-enhanced SRL interventions (Moos & Ringdal, 2012; Wang & Sperling, 2020).
- The relationship between SRL and mathematics achievement (Gabriel et al., 2020).

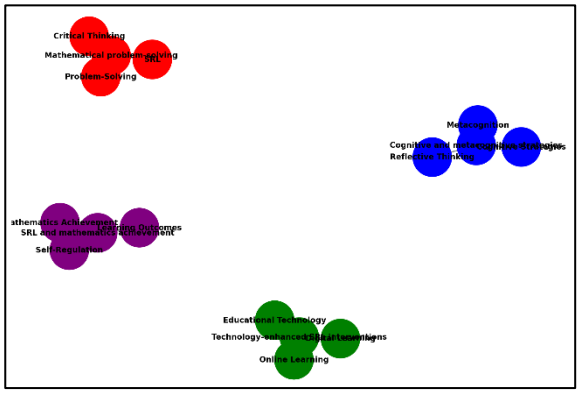

Figure 5. Co-word analysis of mathematical literacy and SRL research

As Table 3 identifies, several key themes guide the construction of novel mathematical literacy and SRL research contributions.

Table 3. Key themes in mathematical literacy and SRL research

Theme	Keywords	Freq
Cognitive Strategies	Metacognition, problem-solving, reflection	12
Motivation & Emotion	Academic resilience, mathematics anxiety, self-efficacy	10
Pedagogical Approaches	Inquiry-based learning, scaffolding, flipped classroom	8
Technological Integration	Digital literacy, online learning, AI-assisted tutoring	6

Assessment & Measurement	Mathematical reasoning, test performance, formative assessment	5

- Cognitive Strategies: Studies emphasize the importance of metacognition, problem-solving, and reflection in fostering mathematical literacy and self-regulation (Wang & Sperling, 2020).
- Motivation & Emotion: Research highlights how academic resilience and self-efficacy influence students' ability to engage with mathematics learning autonomously (Cheung, 2017; Gabriel et al., 2020).
- Technological Integration: The role of digital tools, AI-assisted learning, and e-learning platforms is gaining traction as effective means to enhance mathematical literacy and self-regulated learning strategies (Kramarski, 2012; Wang & Sperling, 2020).

These findings highlight the integration of SRL into mathematics curricula, emphasizing metacognition, technology-based learning, and its role in enhancing problem-solving skills.

4. Patterns of Collaboration Among Authors and Countries

Co-Authorship Analysis: Research Collaboration Networks. Co-authorship analysis reveals that research in mathematical literacy and SRL is highly collaborative, particularly among European, North American, and Australian institutions. Figure 6 illustrates the global research collaboration network.

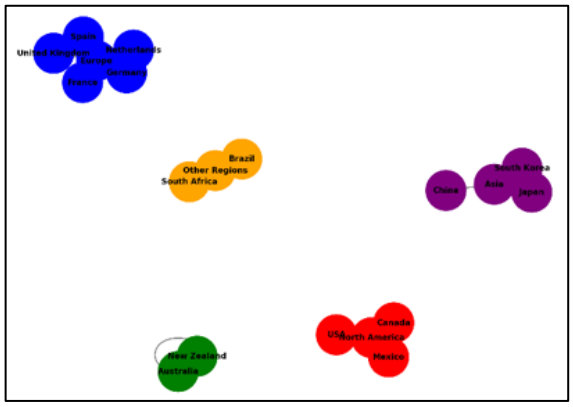

Figure 6. Global collaboration in mathematical literacy and SRL research

Figure 6: Global Collaboration in Mathematical Literacy and SRL Research illustrates the global research collaboration network. Different colors represent collaboration among countries based on regions:

- Blue: Collaboration in Europe (Germany, France, United Kingdom, Netherlands, Spain).
- Red: Collaboration in North America (USA, Canada, Mexico).
- Green: Collaboration in Australia and New Zealand.
- Purple: Collaboration in Asia (China, Japan, South Korea).
- Orange: Collaboration in Other Regions (Brazil, South Africa).

Findings suggest that cross-institutional and interdisciplinary collaborations have contributed significantly to advancing research on mathematical literacy and SRL (Losenno et al., 2020; Panadero, 2017).

Discussion

1. Trends in Publication and Citation in Mathematical Literacy and SRL (2009–2023)

The analysis of publication trends in mathematical literacy and self-regulated learning (SRL) between 2009 and 2023 reveals a fluctuating yet increasing research focus on this field. The overall trajectory shows that interest in mathematical literacy and SRL research grew significantly after 2015, reaching its peak in 2021 and 2022. This rise is consistent with broader educational shifts toward competency-based learning, problem-solving, and self-directed learning (Panadero, 2017).

The trend aligns with the growing recognition of self-regulated learning as a critical component of mathematical proficiency, as evidenced by studies emphasizing metacognition, motivation, and strategic learning behaviors (Wang & Sperling, 2020). The peak in 2021 and 2022 may be linked to increased global interest in adaptive learning technologies, which have been increasingly integrated into mathematics education to enhance SRL strategies (Gabriel et al., 2020).

However, while publication output has increased, the citation analysis presents a more complex picture. The most influential studies in mathematical literacy and SRL were primarily published between 2012 and 2018, indicating that foundational research from this period continues to shape contemporary discourse. The works of (Kramarski & Mizrachi, 2006; Moos & Ringdal, 2012) remain highly cited, highlighting their impact on theoretical advancements in self-regulated learning and its application in mathematics. Despite newer publications, citation growth has been inconsistent, suggesting that not all studies achieve significant scholarly influence. This highlights the need for greater theoretical consolidation, interdisciplinary engagement, and methodological rigor to enhance the long-term impact of research in this field (Losenno et al., 2020; Wang & Sperling, 2020).

One explanation for this variability in citation patterns is the divergence in research methodologies. Some studies focus on conceptual and theoretical aspects of SRL, while others examine empirical interventions in classroom settings. While enriching the field, this methodological diversity may also contribute to fragmentation in the research landscape, making it challenging to establish unified theoretical foundations (Harding et al., 2019). Future research should bridge these gaps by integrating quantitative and qualitative methodologies to produce more generalizable and practically applicable findings (Özcan, 2016).

2. Most Influential Documents, Authors, Institutions, and Countries

The most-cited studies in mathematical literacy and SRL focus on four significant thematic contributions:

1. The Conceptualization of Self-Regulated Learning in Mathematics Education – Boekaerts (2016) provided one of the most comprehensive frameworks, explaining how students regulate their mathematical thinking through metacognitive strategies, motivation, and self-reflection.
2. The Relationship Between SRL and Mathematical Problem-Solving – (Özcan, 2016) explored how students with higher self-regulation skills perform better in mathematical problem-solving, supporting the integration of SRL into mathematics curricula.
3. Teacher Roles in Supporting SRL in the Classroom – (Moos & Ringdal, 2012) emphasized the importance of scaffolding and instructional design in promoting self-regulated learning in mathematics.
4. The Role of Motivation and Mathematics Anxiety in SRL – (Gabriel et al., 2020) examined how mathematics anxiety and self-efficacy interact with self-regulated learning behaviors, influencing students' mathematical achievement.

The leading authors and institutions in mathematical literacy and SRL research are primarily concentrated in the United States, Australia, and Europe. Universities such as the University of Leuven, Wake Forest University, and the Australian Catholic University have contributed significantly to this research area, reflecting global educational priorities (Pintrich & Blazevski, 2004). Turkey has emerged as a notable contributor, particularly through Özcan's work on SRL and mathematical problem-solving. This suggests that self-regulated learning research is gaining prominence beyond Western institutions, indicating an increasing global interest in its application to mathematics education (Cheung, 2017).

3. Thematic Analysis of Mathematical Literacy and SRL Research

The co-word analysis identified four dominant themes in mathematical literacy and self-regulated learning:

1. Mathematical Problem-Solving and SRL – Research confirms that students who actively regulate their learning process exhibit better problem-solving abilities and resilience when tackling mathematical challenges (Özcan, 2016; Wang & Sperling, 2020).

2. Cognitive and Metacognitive Strategies – Studies emphasize that metacognition, cognitive awareness, and reflective thinking are essential for mathematical literacy. Teaching these strategies explicitly can improve students' mathematical reasoning and learning autonomy (Boekaerts & Niemivirta, 2000; Kramarski & Mizrachi, 2006).
3. Technology-Enhanced SRL Interventions – Digital learning environments are increasingly important in SRL research. Technology can provide personalized feedback, adaptive learning pathways, and real-time self-monitoring tools, which help develop self-regulated learning habits in mathematics (Kramarski, 2012; Moos & Ringdal, 2012).
4. SRL and Mathematics Achievement – There is strong evidence that students who actively engage in self-regulation strategies tend to perform better in mathematics. Research highlights the role of motivation, self-efficacy, and academic resilience in shaping students' mathematical outcomes (Cheung, 2017; Gabriel et al., 2020).

These findings reinforce the need to integrate SRL principles into mathematics curricula, focusing on metacognition, technology-based learning, and problem-solving strategies (Panadero, 2017).

4. Patterns of Collaboration Among Authors and Countries

The co-authorship analysis reveals that research in mathematical literacy and SRL is highly collaborative and globally distributed. The United States, Europe, and Australia dominate research output, while Asia and Latin America are emerging contributors.

European countries, such as Germany, France, the UK, Netherlands, and Spain, form strong research clusters, reflecting their long-standing focus on self-regulated learning and mathematics education reform. Similarly, in North America, research output is concentrated in the USA, Canada, and Mexico, focusing on educational interventions and cognitive science applications in mathematics (Losenno et al., 2020).

Asia's growing engagement in SRL research is reflected in studies from China, Japan, and South Korea, where educational policies emphasize structured learning, metacognition, and high-stakes mathematical assessments (Cheung, 2017). Meanwhile, Brazil and South Africa have begun to develop cross-disciplinary collaborations, signaling an increasing interest in self-regulation and mathematics education in non-Western contexts.

These findings suggest that interdisciplinary and cross-institutional collaborations will be critical in advancing research in this field. Increased cooperation between Western and non-Western educational systems could foster a more globally representative understanding of mathematical literacy and SRL (Panadero, 2017).

The Construction of Novelties in Mathematical Literacy and Self-Regulated Learning Research

The development of research in mathematical literacy and self-regulated learning (SRL) has led to the emergence of novel contributions that shape current and future trends in the field. Through a thematic and bibliometric analysis, we identify key areas of innovation that define the advancement of mathematical literacy and SRL. These include cognitive strategies, motivation and emotion, pedagogical approaches, technological integration, and assessment methodologies. Each theme represents an essential dimension in the evolution of self-regulated learning research in mathematics education.

1. Cognitive and Metacognitive Strategies in SRL Research

A fundamental innovation in mathematical literacy and SRL research is the emphasis on cognitive and metacognitive strategies. Studies have shown that self-regulated learners actively monitor and control their cognitive processes, allowing them to develop

problem-solving skills, reasoning abilities, and mathematical literacy (Kramarski & Mizrachi, 2006). The application of metacognitive reflection, goal setting, and self-assessment has been widely explored, with research emphasizing the role of structured interventions in guiding students toward independent mathematical thinking (Boekaerts, 2016).

Recent research has focused on how explicit metacognitive instruction can foster mathematical literacy. For example, (Wang & Sperling, 2020) highlights the importance of self-explanation techniques and cognitive monitoring in helping students build connections between mathematical concepts. Similarly, (Özcan, 2016) explored how problem-solving frameworks that integrate metacognitive questioning enhance students' ability to tackle complex mathematical problems.

Integrating self-reflective practices into mathematics curricula is an emerging trend that aligns with competency-based learning approaches. Future research should focus on developing scalable instructional models that enable teachers to embed metacognitive strategies within everyday mathematics instruction, ensuring that students can apply SRL beyond structured learning environments.

2. Motivation and Emotional Factors in Mathematical Literacy and SRL

Another emerging focus in the field is the role of motivation, emotions, and self-efficacy in self-regulated learning. Motivation is a key determinant of students' ability to engage in self-directed learning, particularly in mathematics, where anxiety and confidence levels play a significant role in performance (Cheung, 2017; Gabriel et al., 2020).

Studies have increasingly examined the relationship between mathematics anxiety, academic resilience, and SRL strategies. (Gabriel et al., 2020) students with higher levels of self-efficacy and emotional regulation are more likely to develop robust SRL skills, allowing them to persist in problem-solving despite challenges. (Cheung, 2017) further supports this claim, highlighting that students who exhibit academic resilience tend to adopt adaptive SRL strategies, such as strategic planning and reflective thinking, which lead to better mathematical literacy outcomes.

Innovative studies are now exploring how effective interventions, such as growth mindset training and stress-reduction techniques, can complement SRL development in mathematics education. Future research should explore personalized learning pathways catering to students' emotional and motivational profiles, ensuring that interventions are inclusive and effective across diverse learning populations.

3. Pedagogical Approaches and Instructional Design for SRL in Mathematics

A significant body of research has focused on pedagogical innovations that integrate SRL into mathematics instruction. Traditional teacher-centered models are increasingly replacing student-centered approaches, emphasizing active learning, inquiry-based instruction, and scaffolding techniques (Moos & Ringdal, 2012; Panadero, 2017).

The flipped classroom model, where students engage with instructional content before class and apply knowledge through problem-solving activities, has been identified as an effective method for fostering SRL (Wang & Sperling, 2020). This approach allows students to take greater ownership of their learning, reinforcing self-regulatory behaviors such as goal-setting, self-monitoring, and self-reflection.

Another pedagogical trend is collaborative learning and peer-assisted SRL, which encourages students to engage in discussions, justify their reasoning (Scristia, Dasari & Herman, 2023), and co-regulate their learning processes (Özcan, 2016). Studies indicate that students who participate in structured peer discussions show higher levels of engagement and metacognitive awareness, leading to improved mathematical literacy.

Future innovations in pedagogy should focus on developing scalable models that integrate SRL strategies into various instructional

frameworks. This would ensure that both teachers and students have structured yet flexible learning environments to support self-regulated growth in mathematics.

4. Technology-Enhanced Learning and SRL Interventions

One of the most transformative developments in SRL research is the integration of technology-enhanced learning environments. With the rise of artificial intelligence (AI), adaptive learning platforms, and intelligent tutoring systems, SRL strategies are increasingly supported through personalized, data-driven feedback mechanisms (Kramarski, 2012; Wang & Sperling, 2020).

Moos and Ringdal (2012) explored how computer-assisted learning platforms can enhance self-monitoring and metacognitive reflection by providing real-time feedback and personalized learning pathways. Similarly, Gabriel et al. (2020) found that digital platforms incorporating gamified learning experiences promote student engagement, self-efficacy, and long-term retention of mathematical concepts.

Recent innovations include AI-driven intelligent tutors that provide automated scaffolding, helping students regulate their learning independently of direct teacher intervention (Panadero, 2017). These tools enable students to set learning goals, track progress, and receive immediate feedback, reinforcing self-regulation through iterative practice.

Future research should explore how emerging technologies, such as AI-powered learning analytics and virtual reality simulations, can further support SRL development in mathematics education. Additionally, ensuring equitable access to digital SRL interventions is crucial, as technology-based learning should be accessible to diverse populations and adapted to different educational contexts.

5. Assessment and Measurement of SRL in Mathematical Literacy

One of the most pressing challenges in the field is assessing self-regulated learning and its impact on mathematical literacy. Unlike traditional measures of academic achievement, SRL requires multidimensional assessment tools that capture cognitive, behavioral, and emotional regulation processes (Wang & Sperling, 2020).

Current research explores self-report questionnaires, learning analytics, and process-tracing methodologies as tools for evaluating SRL in mathematical contexts. (Özcan, 2016) suggests that eye-tracking and think-aloud protocols provide valuable insights into how students monitor and adjust their learning strategies in real-time.

Additionally, formative assessment practices, such as reflective journals and digital dashboards, are being increasingly adopted to help students track their progress in self-regulation. These tools allow learners to engage in self-assessment and goal-setting, reinforcing metacognitive awareness and continuous improvement (Gabriel et al., 2020).

Future research should develop integrated assessment frameworks that combine traditional performance measures with dynamic self-regulation indicators, ensuring that SRL competencies are accurately captured and translated into actionable instructional strategies.

Limitations and Suggestions

Despite the comprehensive insights provided by this study, several limitations must be acknowledged. First, the scope of the bibliometric analysis is limited to studies indexed in Google Scholar and extracted via Publish or Perish. These tools were selected due to their accessibility, wide coverage across disciplines, and inclusion of open-access publications and gray literature, sometimes unavailable in subscription-based databases like Scopus or Web of Science. However, it is acknowledged that this choice may exclude high-impact research indexed exclusively in other databases. Future studies should consider integrating broader and more curated databases, such as Scopus or Web of Science, to ensure more representative and comprehensive coverage.

Second, while this study identifies publication and citation trends, thematic developments, and collaboration patterns, it does not deeply analyze the methodological quality of the included studies. Future research should incorporate systematic content analysis to evaluate the effectiveness of SRL interventions and instructional strategies in mathematical literacy.

Third, the co-word and co-authorship analyses provide valuable insights into research connections but do not fully capture the interdisciplinary nature of SRL research. Expanding the analysis to include cross-disciplinary influences from cognitive science, psychology, and educational Technology would provide a more holistic perspective.

Finally, this study primarily focuses on global trends, with limited discussion of regional or country-specific educational policies that shape SRL implementation. Future research should explore contextual variations in SRL and mathematical literacy practices across different educational systems, ensuring that findings apply to diverse learning environments.

To address these limitations, future research should:

1. Expand database selection to include Scopus, Web of Science, and ERIC for a broader literature review.
2. Integrate qualitative systematic reviews to assess SRL's pedagogical and instructional effectiveness in mathematics education.
3. Explore interdisciplinary connections between SRL research and neuroscience, AI-driven learning, and motivation studies.
4. Examine country-specific policies to understand how cultural and systemic factors influence SRL development in different regions.

By addressing these areas, future studies can strengthen SRL research's theoretical and practical contributions, ensuring the effective implementation of self-regulated learning strategies in mathematical literacy education worldwide.

IV. Conclusion

This scoping review and bibliometric analysis provide key insights into developing research on mathematical literacy and self-regulated learning (SRL) from 2009 to 2023. The findings indicate a steady publication growth, particularly after 2015, reflecting increasing academic attention toward competency-based education, metacognition, and digital learning. The most cited works emphasize SRL's impact on problem-solving, student motivation, and technology-supported interventions, while Western institutions remain central in shaping research directions.

Despite this progress, citation patterns remain inconsistent, and cross-cultural perspectives remain limited. Most research is concentrated in North America, Europe, and Australia, with minimal representation from Asia, Latin America, and Africa. This highlights a need for more inclusive, globally representative studies.

Research should explore interdisciplinary approaches integrating AI-driven learning, personalized feedback, and adaptive assessment tools. Additionally, teacher training in SRL-centered pedagogies remains a critical gap. Future studies must address theoretical, contextual, and pedagogical dimensions to ensure SRL strategies can effectively support mathematical literacy development in diverse learning environments.

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