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Metacognition in mathematics education: From academic chronicle to future research scenario–A bibliometric analysis with the Scopus database

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Abstract

Originally introduced by psychologists, metacognition has attracted considerable interest within academic spheres and has transformed into a significant research focal point in the field of mathematics education, commonly denoted as 'mathematical metacognition.' This investigation constitutes the primary endeavor to comprehensively examine all publications within the Scopus database related to metacognition in mathematics education (MiME). The data encompasses a total of 288 documents, authored by 653 individuals hailing from 58 different countries and territories and disseminated across 162 diverse sources. Notably, this examination delineates two distinct developmental phases, with a particularly pronounced surge in publications emerging from the year 2016 onward. Although Asia has two representatives in the top-10 in terms of number of publications (China and Indonesia), authors from developed countries have made significant contributions to research on MiME, especially the United States, Germany, Turkey, and Belgium. Among the 15 most influential academic journals, merely two pertain to the domain of mathematics education, whereas the majority belong to the disciplines of psychology and social sciences (educational science). The main research directions that have been pointed out are adults' metacognitive abilities, considering gender differences and problem-solving abilities; metacognition and the ability to learn mathematical concepts (more recently arithmetic concepts); control metacognitive processes and students' academic achievement. Early-career researchers as well as interested scholars can find important scholars, documents, and research directions on this topic to refer to for their research activities.

Keywords: metacognition, mathematical metacognition, mathematics education, bibliometric, research trend

INTRODUCTION

Originally coined by Flavell (1971), the term '*metamemory*' triggered a significant research trend on concepts related to the 'meta-' prefix over the past four decades. The concept of 'metacognition' was officially introduced by Flavell (1976), referring to "… one's knowledge concerning one's own cognitive processes, or anything related to them (…) [and], among other things, to the active monitoring and consequent regulation and orchestration of these processes …" Metacognition, in short, is "thinking about thinking, cognition about cognition" (Flavell, 1976). This definition emphasizes the executive role of metacognition in monitoring and regulating cognitive processes. In the light of this definition, metacognition-related terms are utilized and interpreted in various forms, namely Metacognitive beliefs, metacognitive awareness, metacognitive experiences, metacognitive knowledge, judgments of knowing, feeling of knowing, metamemory, metacognitive skills, metacognitive knowledge monitoring, meta comprehension, and self-regulation, theories of mind, etc. (Brown et al., 1983; Flavell, 1979; Nelson & Narens, 1990; Schraw & Moshman, 1995; Tobias & Everson, 1995, 1999, 2001). The current metacognition concept focuses on the enhancement of learning to facilitate individuals in adapting, accepting,

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Contribution to the literature

- Scientific data on the existing literature on MiME are presented systematically for the first time.
- This study has revealed the main research trends and recommendations for future research directions on MiME.
- This study has identified the most notable authors, works and journals that have had the greatest impact on research trends in MiME.

and self-regulating in accordance with changes in the surrounding environment.

Research on metacognition derived from memory development (also called meta-memory) (Dunlosky & Tauber, 2016). Metacognitive potentials were soon recognized in various domains such as reading comprehension (Baker, 1989), mathematics (Schneider & Artelt, 2010), particularly mathematical metacognition (Desoete, 2008), which indicates the considerable correlation between learners' metacognitive knowledge and competence and their academic achievements. Metacognition pertains to individuals' ability to self-regulate their learning, including awareness of their strengths and weaknesses as well as the recognition of useful strategies to make progress in specific tasks (for example: how well an individual can monitor progress during the process of completing a task and to what extent they can identify necessary behavioral changes to achieve the target) (Muncer et al., 2021).

Initially, metacognition research primarily focused on metacognition in reading (Stillman & Mevarech, 2010). However, there has been more research works on mathematical education, specifically problem-solving issues (Schoenfeld, 1983a, 1983b, 1985, 1987), which has always been an inspirational research topic within the area of metacognition in mathematics education (MiME) today (Stillman & Mevarech, 2010).

In mathematics education, metacognition is confirmed in various studies as one of the most significant predictors of mathematical students' academic achievements (Kuzle, 2018; Ohtani & Hisasaka, 2018; Schneider & Artelt, 2010) with considerable impacts on metacognitive knowledge instruction in mathematics teaching (Donker et al., 2014; Hacker et al., 2019; Lucangeli et al., 2019). It has been shown in previous studies that children with insufficient metacognitive development are likely to struggle with mathematics (Desoete & De Craene, 2019). As metacognition is a teachable skill (Baten et al., 2017; Shilo & Kramarski, 2019), it is recommended to provide instruction for children to get access to metacognitive-mathematical discourse, thereby developing and perceiving the necessity of metacognitive skills. Nevertheless, there is still controversy over the beneficial effects of metacognitive strategies on learners' mathematics education process (Desoete & De Craene, 2019).

In 2019, ZDM, International Journal on Mathematics Education, published a special volume on "metacognition in mathematics education" focusing on the assessment and development of potential metacognition with the aim of positively influencing learners' mathematics learning process (Desoete & De Craene, 2019). Unluckily, neither in this special volume nor in previous studies can the authors obtain a review of MiME research trends, as well as the most influential authors, research works and sources on this topic. This study, therefore, aims to provide an overview of MiME research over the last four decades.

This study analyzes and identifies the growth patterns of publication volume, outstanding authors, publications, sources and countries in MiME research works to draw an overall picture of MiME publications worldwide. Also, the study points out research gaps and proposes some recommendations for potential future research directions. Specifically, our study seeks to answer the following research questions:

RQ1. What are the volume, growth model, and geographical distribution of metacognition publications?

RQ2. What are the influential authors, publications, and sources (journals/books) on metacognition?

RQ3. What are the key subjects in existing literature on metacognition?

To fulfill the research objectives, bibliometric analysis methods were employed with the Scopus database, one of the largest academic databases all over the world (Hallinger & Nguyen, 2020; Nguyen et al., 2023; Pham et al., 2022; Phan et al., 2022).

In the next sections, metacognition and MiME concepts are discussed, followed by data collection procedures and data analysis methods of the study. Subsequently, the Findings section presents the answers to above mentioned research questions. Finally, the researchers discuss and conclude the research issues, then recommend suggestions for further research on this critical topic in mathematics education.

METACOGNITION & METACOGNITION IN MATHEMATICS EDUCATION

Metacognition

The concept of 'metacognition' or 'thinking about thinking' was first mentioned by Flavell (1976) as meta-knowledge, originally coined as 'metamemory' (Flavell, 1971). It was then upgraded by Flavell (1976, p. 232) himself by defining metacognition as "... one's knowledge concerning one's own cognitive processes, or anything related to them and the active monitoring and consequent regulation and orchestration of these processes ..." Subsequently, metacognition was defined as any knowledge or cognitive activity that involves cognitive processes as the object (Flavell et al., 2002). Therefore, on the one hand, metacognition pertains to people's knowledge about their own information processing skills, the nature of cognitive tasks, and their cognitive coping strategies. On the other hand, it comprises executive abilities to monitor and self-regulate one's own cognitive activities. In other words, metacognition is a second or higher thinking process related to active control over cognitive processes (Mevarech & Kramarski, 2014, 36). Given a number of definitions and viewpoints on metacognition, it was regarded as a "fuzzy" concept (Akturk & Sahin, 2011) by many scholars, and a number of related terms are still contested (Proust, 2010).

Brown (1987) distinguishes two types of metacognition: "knowledge" about one's own cognitive activities and "regulation" of one's own cognitive activities. Lucangeli et al. (2019) define 'metacognitive knowledge' as an individual's attitudes, knowledge, and emotions about intellectual activities, contributing to understanding the mechanism of different cognitive processes and ones related to mathematics learning. 'Metacognition control' is described as allowing children to assess the difficulty level of a task, plan supporting actions and strategies, and self-monitor potential errors in their thoughts and efficiency.

Most researchers agree on separating 'metacognitive knowledge' from 'metacognitive skills' (Veenman, 2006). Thus, there is a gap between being aware of metacognition and being capable of successfully using the skills to fulfill new tasks. Desoete et al. (2019) differentiate 'metacognitive knowledge' from 'metacognitive skills' and state that metacognitive accuracy in post-diction might be used as a relevant indicator of metacognition and mathematics performance. 'Metacognitive skills' are regarded as executive functions of metacognition or required procedural knowledge to monitor and control one's actual learning activities (Veenman, 2006).

Some approaches classify metacognition into multiple components. It is believed by numerous scientists that metacognition comprises two basic components: knowledge about cognition and regulation of cognition (Flavell, 1979; Schraw & Moshman, 1995). Flavell (1979) proposed three types of metacognitive knowledge

(1) knowledge of person variables–'everything that you could come to believe about the nature of yourself and other people as cognitive processors',
(2) task variables–'the information available to you during a cognitive enterprise', and
(3) strategy variables–'knowledge that could be acquired concerning what strategies are likely to be effective in achieving what subgoals and goals in what sorts of cognitive undertaking'.

Flavell (1979) emphasizes that in most cases, metacognitive knowledge is the combination of two out of the three types above. According to Brown and Palincsar (1982), regulation of cognition refers to executive control in information processing models including preplanning and planning in action, planning and control, pre-action and trouble-shooting, and planning and monitoring. Schraw and Moshman (1995) state that regulation of cognition involves activities that help regulate the thinking or learning process. It consists of fundamental skills, namely planning, monitoring, and evaluation (Jacobs & Paris, 1987; Kluwe, 1987; Schraw & Moshman, 1995).

Moreover, Flavell (1979) describes the components of metacognition in the cognitive monitoring/regulation model including

(a) metacognitive knowledge,
(b) metacognitive experiences,
(c) goals or tasks, and
(d) actions or strategies.

Flavell (1979) concluded that monitoring cognitive processes operates via actions and interactions between metacognitive knowledge; metacognitive experience; the task or cognitive goals and strategies/actions. This model serves as the foundation for the development of metacognition theory as the components of metacognition and their interactions were defined and clarified for the very first time.

Metacognition in Mathematics Education

Being aware of the role and significance of metacognition in learning, many mathematics educators have conducted research on MiME. Mathematics metacognition is a special kind of metacognition based on metacognitive knowledge and involves evaluating, monitoring, and regulating mathematics cognitive processes (Shen & Chen, 2014). It is evident that primary school students' level of mathematics metacognition shows a considerably significant correlation with mathematics learning achievements and that high-achievers of mathematics metacognition tend to gain good achievements in mathematics learning (Fernie et al., 2018; Zhang et al., 2018). Meanwhile, empirical findings also reveal the growing correlation between metacognitive skills and age-based mathematics learning in contrast to the relative independence of these skills from intellectual development (Veenman &

Spaans, 2005). Metacognitive learners in mathematics are active participants in their own learning process. They are meta-aware of planning, setting goals, deciding strategies, organizing, self-monitoring and self-evaluating at multiple times throughout the learning process (Schoenfeld, 1992; Schraw, 1998). Less metacognitive learners are rarely capable of gaining good learning achievements because even with great intellectual capacity or motivation, they are unable to plan, evaluate and monitor their own learning process (Kazuhiro & Tetsuya, 2018; Wonjoon et al., 2020).

RESEARCH METHOD

Bibliometric Analysis

Bibliometric analysis has been widely known for its efficiency in scientific publications analysis (Hallinger & Nguyen, 2020; Nguyen et al., 2023; Pham et al., 2020). Based on bibliometric data such as authors, affiliations, keywords, abstracts, publication year, citations, references, etc., this method can conduct quantitative analyses of growth patterns of publications, level of impacts by author, affiliation, country, research collaboration as well as identify research trends over a period of time (Hallinger & Kovačević, 2019; Nguyen et al., 2023; Trinh et al., 2020). Thus, bibliometrics analysis is a suitable approach to address our research questions. In this study, some techniques were employed to analyze the data.

The bibliometric analysis uses both citation and co-citation analysis to ascertain outstanding authors, publications, and journals in a knowledge domain (Do et al., 2021; Hallinger & Suriyankietkaew, 2018; Phan et al., 2022). It calculates the citation number of a publication in others within the examined database. Citation data includes the total number of citations and citations in each document, and the h-index is the quantitative description of academic impact (Hallinger & Suriyankietkaew, 2018; Zupic & Čater, 2014). Zupic and Čater (2014) claim that "co-citation is defined as the frequency of co-occurrence of two variables (author and journal)" (p. 431) and co-citation analysis uses "co-citation numbers" to set up similar measures across publications, authors or journals. Author co-citation analysis has been used in analyzing the intellectual structure of scientific disciplines. Publication co-citation analysis (or journal) involves pairs of documents (or sources) that are co-cited in source articles. When pairs of similar publications are co-cited by multiple authors, it is possible to identify thematic clusters as co-cited publications in a cluster tend to have common research themes. Thus, publication co-citation analysis can create structure science mapping of specialized research fields.

Co-word analysis technique allows the researchers to discover metacognition structure, and highlight "hot" topics and research trends (Hallinger & Nguyen, 2020; Zupic & Čater, 2014). Keyword co-occurrence analysis points out the most common keywords in examined publications by calculating the frequency of co-occurrence of keywords, which offers an insightful description of the most researched topics and concepts in the research field (Zupic & Čater, 2014). The technique assumes that if two keywords co-occur in some publications, these documents are similar thematically and connected. Co-citation analyses by author, documents, and sources can be used to identify the most influential authors, publications, and sources in the research field. Chronological keyword co-occurrence analysis produces a network visualization, which is similar to a co-occurrence network visualization, but its nodes have slightly different colors based on the time of occurrence of the keywords. The nodes with slighter colors represent more recent keyword/key phrases, thereby implying the recent research trends within a field.

Moreover, bibliometric analysis has been widely used in social science and educational science research with various topics such as research on lifelong learning (Do et al., 2021), learning management systems (Pham et al., 2022), mathematical education or STEM education (Julius et al., 2021; Phan et al., 2022; Zhan et al., 2022), internationalization in higher education (Cao et al., 2021; Pham et al., 2021), sustainable leadership (Hallinger & Suriyankietkaew, 2018), education for sustainable development (Hallinger & Nguyen, 2020), and scientific communication (Nguyen et al., 2020, 2023; Pham et al., 2022).

Data

This study makes use of the Scopus database, one of the most significant, reputable, and resourceful scientific databases with a great number of social sciences sources (Hallinger & Kovačević, 2019; Pham et al., 2020). To seek answers to the research questions, the two keywords "metacognition" and "mathematics" were initially selected. Subsequently, in consultation with the study by Julius et al. (2021) on 'Research in Mathematics Education', the researchers decided to adopt the keywords related to "edu", "teach", "learn", "train", "pedagogy", and "student". Finally, the following search query was used to retrieve the Scopus database (on 5 September 2023): TITLE-ABS-KEY ("mathematics" AND "metacognit*" AND (edu* OR teach* OR learn* OR train* OR pedagogy OR student* OR curricul*)) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SUBJAREA, "SOCI")) AND (LIMIT-TO (LANGUAGE, "English")).

Preferred reporting items for systematic reviews and meta-analyses (PRISMA) was applied to ensure the quality of the document search processing (Moher et al., 2009). The proceeding steps are described, as follows:

Step 1. Identification

In this step, following document analysis and search query finalization, the researchers retrieved 484 documents from the Scopus database.

Step 2. Screening

In this stage, each retrieved document was checked for sufficient data fields. Some documents were disqualified due to the irretrievable absence of abstracts or the whole document. Three documents in total were excluded after this step, leaving 481 documents in the database.

Step 3. Eligibility

In this step, the research group studied the retrieved abstracts, keywords, article titles and concluded about the eligibility of the publications for the research topic. Some documents are disqualified due to various reasons, such as irrelevant topics including STEAM education (Gregg-Jolly et al., 2016; Griese et al., 2015), chemistry (Promentilla et al., 2016), physics (Phang, 2010), photography (Cappello & Lafferty, 2015), general metacognition instead of mathematics education (Moulin & Souchay, 2015; Roll et al., 2007; Wall, 2008), or review articles on non-metacognition topics (Baumanns & Rott, 2021). Some documents discussing the concepts of elf-regulatory and self-efficacy in learning without directly mentioning metacognition were secured for processing, such as Ernst et al. (2023) and Jain and Dowson (2009). Some studies were restored after the research group discussion, such as the research on metacognition in multiple subjects, including mathematics by Guo (2020). In some cases, the researchers had to read the full-text articles to make the decision of exclusion due to irrelevant research topics (for example De Clercq et al., 2000). Eventually, there were 193 disqualified documents, and 288 documents retrieved for data analysis.

Step 4. Inclusion

Finally, eligible data for analysis comprises 288 documents. VOSviewer, Biblioshiny, and Microsoft Excel software were employed for data analysis. VOSviewer is used to identify and present profound insights into the relationships between the frequently-used keywords (Merigó et al., 2018). By using keyword co-occurrence analysis, the authors created network visualization of keywords in different documents. Keyword co-occurrence analysis or co-word analysis is recognized as an effective technique to ascertain research themes (Wang et al., 2017). This technique, therefore, is hoped to identify “hot topics” in metacognition research based on keyword development (Lozano et al., 2019). Last but not least, the key sources in the study were defined as the journals, where most publications on metacognition were published. Subsequently, Biblioshiny and Microsoft Excel software were deployed to calculate the number of annual publications by country, author or source as well as number of citations.

RESULTS

Volume, Growth Patterns, & Geographical Distribution of Metacognition Publications

To answer **RQ1**, the research group analyzed 288 publications by 653 authors from 58 countries, published in 162 sources from 1983 to 2023. **Table 1** presents the general information about the data.

Table 1. General information about data

Content	Result
General information about data	
Period	1983:2023
Number of data sources	162
Total number of documents	288
Average number of citations per document	25.35
Total documents cited	13,245
Document content	
Total keywords	312
Author’s keywords (DE)	692
Author	
Total authors	653
Total authors of single-author document	51
Total authors of multi-author document	602
Author’s collaboration	
Total documents of single author	58
Total documents per author	0.44
Total authors per document	2.7

Furthermore, the growth tendency of publication volume in the target field is presented in **Figure 1**. Given the upward trend in metacognition publication numbers from 1983 to 2023 in **Figure 1**, MiME literature development has experienced two phases:

1. **1983-2015: Inadequate attention phase:** During this phase, MiME topic seemed to be neglected by scholars with merely 114 publications in total over 28 years, which means four publications per year. The figure of publications has picked up significantly since 2009, while there were several early years without any publications.

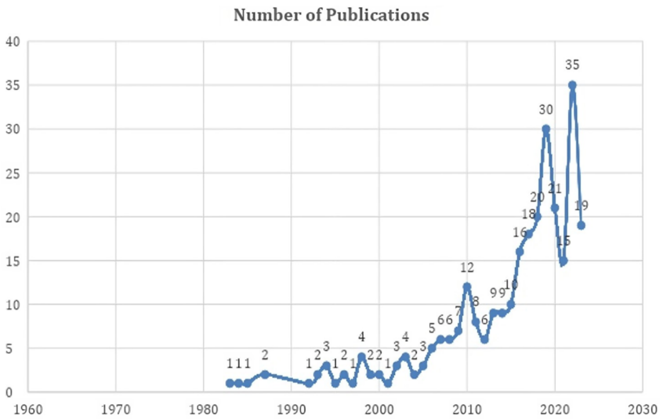

Figure 1. Growth tendency of MiME publications (Source: Authors’ own elaboration, using Excel software)

Table 2. Top-10 countries with the most MiME publications

Rank	Country	Citations	Total citations	Year	Annual average
1	United States	69	2,815	1983-2023	1.725
2	Germany	22	475	2006-2023	1.290
3	Turkey	22	249	2008-2022	1.570
4	Belgium	21	615	2001-2023	1.000
5	Indonesia	18	40	2012-2023	1.630
6	United Kingdom	17	247	1984-2023	0.430
7	Netherlands	14	726	2000-2023	0.600
8	Israel	13	476	1995-2022	0.480
9	China	12	103	2014-2023	1.300
10	Spain	11	203	2000-2023	0.470

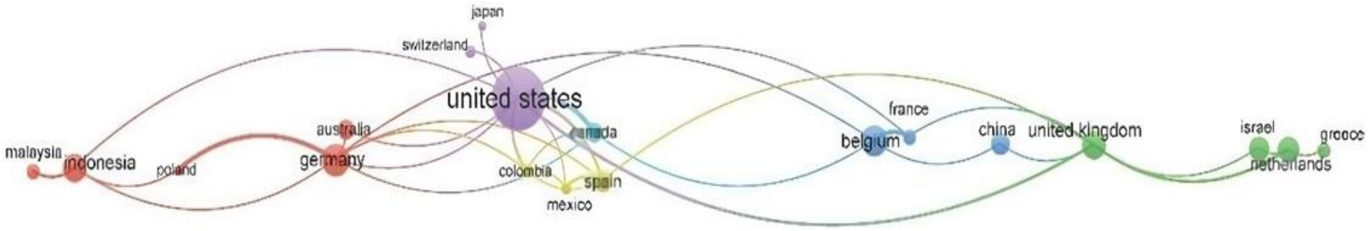

Figure 2. Collaboration between countries in MiME publications (minimum three publications & 25 thresholds) (Source: Authors' own elaboration, using VOSviewer software)

2. **2016-2023: Development phase:** In this period, MiME topic has received considerable attention from academics with the average number of publications annually tripled the figure of the previous phase, at 21.1 publications per year. The total publications within eight years of this stage was 174 documents, which is 1.5 times as many as the total figure for 33 years of the previous phase and accounts for 60% of all publications.

However, it can be seen from **Figure 1** that even in the robust development phase, there has always been fluctuations in yearly publications on MiME. Specifically, there were 15 publications on metacognition in 2021, much fewer than the figures in the previous and following years. It can be partly explained with the impact of the COVID-19 pandemic on academic publications in general.

Table 2 lists the most prolific countries on the topic MiME in the world. As seen from **Table 2**, documents on this topic were mainly published in Europe, America, and some Asian countries, despite a much smaller number of publications.

Figure 2 and **Table 2** illustrate the geographical distribution of MiME publications by country. Authors from 58 countries (co-)published at least one publication on this topic. The United States tops the list of top-10 countries with the most publications on MiME with 69 documents. Subsequently, Germany, Turkey, and Belgium had 22, 22, and 21 publications on MiME, respectively, which are roughly equal to one-third of the US figure. Indonesia followed with 18 publications, becoming the most prolific Asian country regarding MiME publications.

The visualization above highlights several groups of countries with frequent collaboration in MiME publications including:

(1) Indonesia, Germany, Malaysia, Poland and Australia;

(2) United States, Japan, Switzerland;

(3) Spain, Columbia, Mexico;

(4) Belgium, France, China; and

(5) United Kingdom, Israel, Netherland, and Greece.

It is obviously shown in the map that the United States, Germany and United Kingdom acted as the most active elements in international collaboration in this field.

Authors, Documents, & Remarkable Sources

As discussed above, 653 authors published and co-published 288 publications on MiME. Due to characteristics of research collaboration, in **Table 3**, 22 authors with the most cited publications on MiME are presented in descending order of total publications and citations in the Scopus database. Most of them come from developed nations, including North America and Europe. There is no Indonesian author, which implies the absence of major influence from this country in MiME publications.

Alice F. Artzt and Eleanor Armour-Thomas are two most-cited authors (255 citations apiece) in the data collection. They are colleagues at Department of Secondary Education and Youth Services, Queens College of the City University of New York and shared some publications together.

Table 3. 22 most cited authors in MiME publications

R	Author group	Author	Affiliation	Country	h	LC	TC	NP	PY
1	Artzt and Armor-Thomas	Artzt, A. F.	City University of New York	United States	7	255	341	12	1992
		Armor-Thomas	City University of New York	United States	6		374	15	1994
2	Carr and Jessup	Carr	University of Georgia	United States	2	143	21	4	2009
		Jessup	University of Georgia	United States	3		172	3	1995
3	Desoete	Desoete	Universiteit Gent	Belgium	27	108	1,566	98	2000
4	Desoete and Roeyers	Roeyers, Herbert	Universiteit Gent	Belgium	72	100	12,805	304	1995
5	Callan and Cleary	Callan	Utah State University	United States	13	49	390	26	2014
		Cleary	Rutgers University–New Brunswick	United States	22		1,618	46	2000
6	Kuzle	Kuzle	Universität Potsdam	Germany	5	43	76	11	2013
7	Bellon, Fias, and De Smedt	Bellon	KU Leuven	Belgium	5	42	85	11	2016
		Fias	Universiteit Gent	Belgium	50		4,748	151	1994
		De Smedt	University of Leuven	Belgium	41		3,838	6,652	2003
8	Karaali	Karaali	Pomona College	United States	7	20	142	37	2004
9	Vorhölter	Vorhölter	Universität Hamburg	Germany	4	17	68	13	2017
10	Ning	Ning	Chinese University of Hong Kong	Hong Kong	9	16	321	16	2010
11	Geurten and Lemaire	Geurten	Université de Liège	Belgium	12	15	355	56	2014
		Lemaire	Aix Marseille Université	France	32		1,848	125	1994
12	Gidalevich and Kramarski	Gidalevich	Shaanan Academic Religious Teachers' College	Israel	2	12	12	2	2017
		Kramarski	Bar-Ilan University	Israel	22		1,391	59	1992
13	Jagals and Van Der Walt	Jagals	North-West University	South Africa	2	9	14	5	2016
		Van Der Walt	South African Medical Research Council	South Africa	7		143	16	1987
14	van Velzen	van Velzen	Universiteit van Amsterdam	Netherlands	6	5	78	15	2004

Note. R: Rank; h: h-index; LC: Citations in data collection; TC: Total citations in the Scopus database; PY: Year of publication of first publication; & NP: Number of publications

Meanwhile, according to the total citations, the most influential authors are Fias, W. (4,748 citations), de Smedt, B. (3,838 citations), Lemaire, Patrick (1,848 citations). Fias, W. (Faculty of Psychology and Educational Sciences, Department of Experimental Psychology, Ghent University, Belgium, Scopus h-index=50) published mainly on working memory and mathematical cognition. Meanwhile, de Smedt, B. (Faculty of Psychology and Educational Sciences, Parenting and Special Education, KU Leuven, Belgium, Scopus h-index=41) focuses on psychology in mathematics education for preschoolers and primary school students.

Next, the research group identified the most influential articles in this field. Table 4 presents the top 15 most-cited publications from 1983 to 2023. The most cited one was published in 1987 by Metcalfe, J. and Wiebe, D. entitled "Intuition in insight and non-insight problem solving". This study shows that in mathematics education non-insight problems were open to accurate predictions of performance, whereas insight problems were opaque to such predictions (Metcalfe & Wiebe, 1987). All publications in this list were published in the first phase, before 2016.

Moreover, most of the documents in this list were published in journals on social sciences, psychology, and

Table 4. Top-15 most cited publications

R	Reference	Title	Source	LC	TC
1	Metcalfe and Wiebe (1987)	Intuition in insight and non-insight problem solving	Memory & Cognition	430	1,013
2	Veenman and Spaans (2005)	Relation between intellectual and metacognitive skills: Age and task differences	Learning & Individual Differences	275	735
3	Schoenfeld (1983a)	Beyond the purely cognitive: Belief systems, social cognitions, and metacognitions as driving forces in intellectual performance	Cognitive Science	251	1,000
4	Goos et al. (2002)	Socially mediated metacognition: Creating collaborative zones of proximal development in small group problem solving	Educational Studies in Mathematics	225	661
5	Artz and Armour-Thomas (1992)	Development of a cognitive-metacognitive framework for protocol analysis of mathematical problem solving in small groups	Cognition & Instruction	218	784
6	Mevarech and Kramarski (1997)	Improve: A multidimensional method for teaching mathematics in heterogeneous classrooms	American Educational Research Journal	209	608

Table 4 (Continued). Top-15 most cited publications

R	Reference	Title	Source	LC	TC
7	Iiskala et al. (2011)	Socially shared metacognition of dyads of pupils in collaborative mathematical problem-solving processes	Learning & Instruction	183	376
8	Carlson and Bloom (2005)	The cyclic nature of problem solving: An emergent multidimensional problem-solving framework	Educational Studies in Mathematics	155	564
9	Arroyo et al. (2014)	A multimedia adaptive tutoring system for mathematics that addresses cognition, metacognition and affect	International Journal of Artificial Intelligence in Education	142	273
10	Kramarski et al. (2002)	The effects of metacognitive instruction on solving mathematical authentic tasks	Educational Studies in Mathematics	139	511
11	Schneider and Artelt (2010)	Metacognition and mathematics education	ZDM	129	391
12	Veenman et al. (2005)	The relation between intellectual and metacognitive skills in early adolescence	Instructional Science	125	328
13	Desoete et al. (2001)	Metacognition and mathematical problem solving in grade 3	Journal of Learning Disabilities	123	565
14	Ghazal et al. (2014)	Predicting biases in very highly educated samples: Numeracy and metacognition	Judgment & Decision Making	118	223
15	Carr and Jessup (1997)	Gender differences in first-grade mathematics strategy use: Social and metacognitive influences	Journal of Educational Psychology	116	346

Note. R: Rank; LC: Citations in data collection; & TC: Total citations in Google Scholar database

cognitive science, except for only four papers published in two leading journals of mathematics education, namely Educational Studies in Mathematics, and ZDM.

Table 5 lists the 15 journals with publications on MiME, all of which are Q1 journals. The most cited journal was Educational Studies in Mathematics. It is noteworthy that among these 15 journals, there are only two, namely Educational Studies in Mathematics and ZDM, related to mathematics education. Others focus on education or psychology.

Key Topics in Metacognition in Mathematics Education Publications

Figure 4 depicts the results of the keyword co-occurrence analysis with VOSviewer. In the map, the size of the node indicates the number of times that the

Table 5. Top-15 most influential journals on citations

SJR	Source	Publisher	Scope	ISSN	LC	R
1.64	Educational Studies in Mathematics	Springer Netherlands	Mathematics & education	15730816, 00131954	738	Q1
1.37	Learning & Individual Differences	Elsevier BV	Developmental & educational psychology, Education, & social psychology	18733425, 10416080	473	Q1
1.07	Metacognition & Learning	Springer New York	Education	15561631, 15561623	438	Q1
1.40	ZDM	Springer Verlag	Mathematics & education	18639704, 18639690	431	Q1
1.03	Memory & Cognition	Springer New York	Arts & humanities, experimental & cognitive psychology, medicine, & neuropsychology & physiological psychology	0090502X, 15325946	430	Q1
2.40	Learning & Instruction	Elsevier BV	Developmental & educational psychology education	09594752	342	Q1
2.51	Journal of Educational Psychology	American Psychological Association	Developmental & educational psychology education	19392176, 00220663	332	Q1
1.06	Cognitive Science	Wiley-Blackwell	Artificial intelligence, cognitive neuroscience, & experimental & cognitive psychology	03640213, 15516709	254	Q1
0.93	Instructional Science	Springer Netherlands	Developmental & educational psychology education	00204277, 15731952	238	Q1
1.73	Cognition & Instruction	Routledge	Developmental & educational psychology education, experimental & cognitive psychology, & psychology	1532690X, 07370008	218	Q1
2.23	American Educational Research Journal	SAGE Publications Ltd.	Education	00028312, 19351011	209	Q1
1.48	Journal of Learning Disabilities	SAGE Publications Inc.	Education & health & professions & health	15384780, 00222194	186	Q1
1.11	International Journal of Artificial Intelligence in Education	Springer US	Computational theory & mathematics, education, 8 e-learning	15604292, 15604306	142	Q1

Table 5 (Continued). Top-15 most influential journals on citations

SJR	Source	Publisher	Scope	ISSN	LC	R
3.19	Contemporary Educational Psychology	Academic Press Inc.	Developmental & educational psychology & education	0361476X, 10902384	113	Q1
3.80	Journal of Personality & Social Psychology	American Psychological Association	Social psychology, sociology, & political science	00223514	106	Q1

Note. Data was retrieved from scimagojr.com in August 2023; LC: Local citation; & R: Ranking

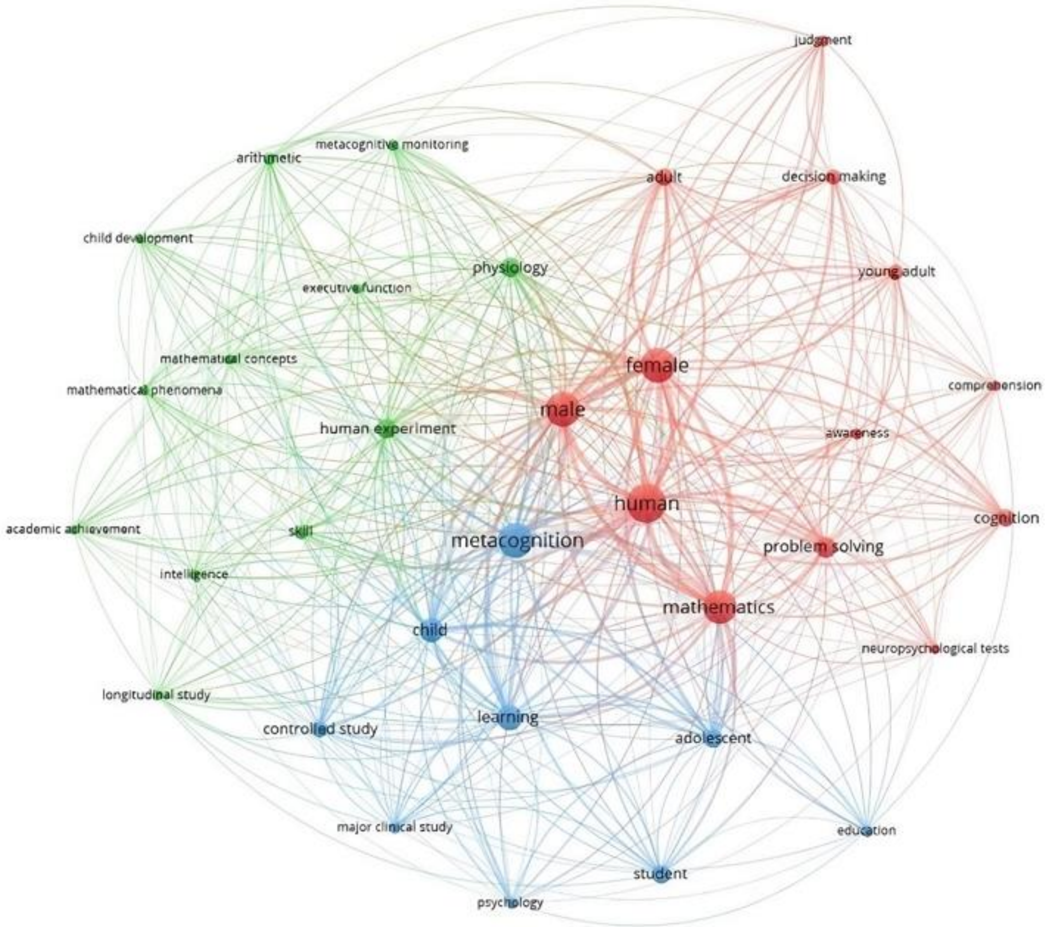

Figure 4. Index keyword co-occurrence map (including 34 keywords with at least four occurrences each) (Source: Authors' own elaboration, using VOSviewer software)

keyword occurs in the data collection and the link between two nodes represents the co-occurrence between the two keywords. In total, there are 308 index keywords in all examined publications.

To establish their relationship, only keywords with more than four occurrences were chosen. Then, there are 34 keywords in the map (wherein some repeated keywords are replaced, for example humans was replaced with human, students with student). The most frequently-occurring keywords are 'human' (34 occurrences), 'male', 'female', and 'metacognition' (29 occurrences), 'mathematics' (27 occurrences), 'learning' (17 occurrences).

Three groups of keywords can be identified from **Figure 4**. The red group consists of 13 keywords: female, male, mathematics, human, adult, awareness, cognition, comprehension, decision making, judgment, neuropsychological test, problem solving, and young adult. This group represents publications on MiME for adults, with considerations to gender distinctions and problem-solving capacity. Most publications in this group pertain to other characteristic metacognitive activities such as purposeful and systematic reflection of cognitive processes, planning, strategies selection, decision making, evaluation, etc. Empirical studies on metacognitive abilities on different subjects in terms of gender and age are also included in the group.

The second group, the green one, comprises 12 keywords: academic achievement, arithmetic, child development, executive function, human experiment, intelligence, longitudinal study, mathematical concepts,

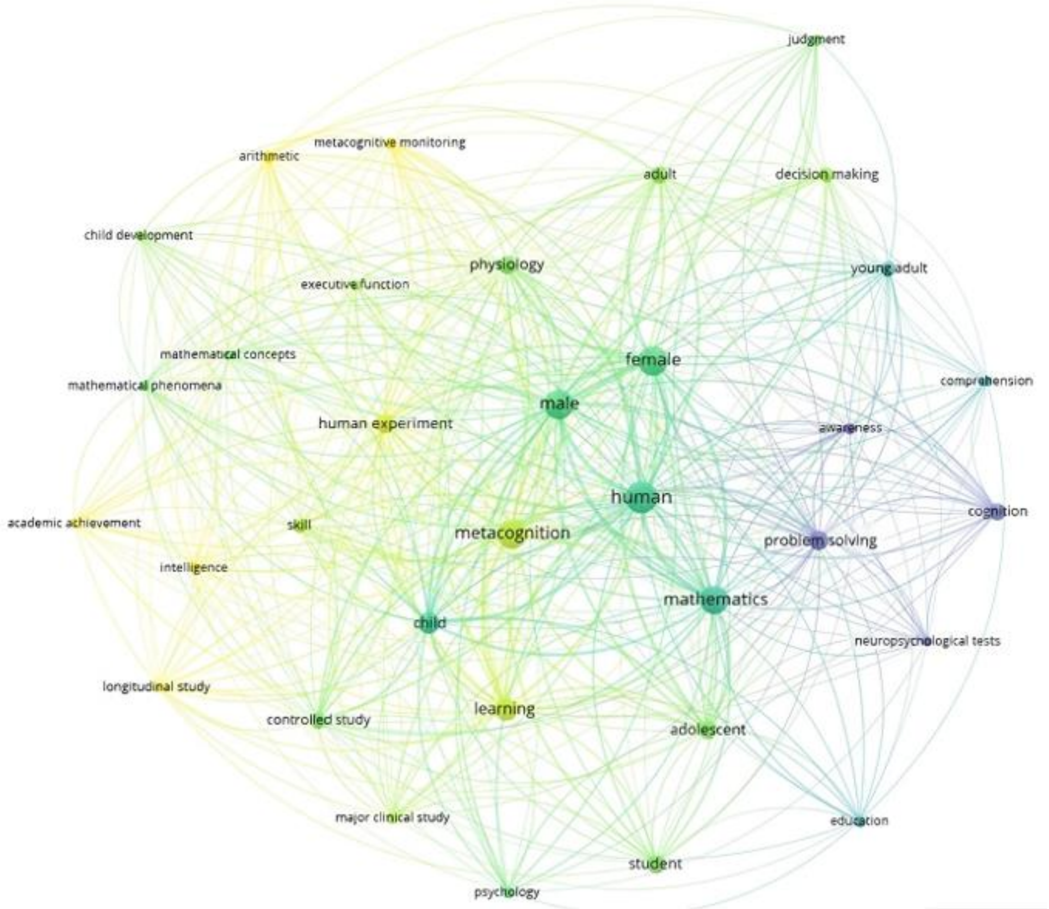

Figure 5. Chronological index keyword co-occurrence map (including 34 keywords with at least four occurrences each) (Source: Authors' own elaboration, using VOSviewer software)

mathematical phenomena, metacognitive monitoring, and physiology. Those keywords indicate a research direction on children's metacognitive ability, the relationship between metacognition and learning achievements, mathematics competence, and intellectual development. Also, studies on metacognition in learning in general and mathematics learning in particular belong to this group. All the nodes in this group have similar sizes, without an obvious locus with significantly higher occurrences.

The third group, the blue one, consists of the keywords: metacognition, child, learning, controlled study, adolescent, major clinical study, psychology, student, education. This group highlights the research directions on children's metacognition, the emergence, chronological development and improvement of metacognitive ability. Besides, the studies in this group discuss the teachability of metacognitive skills and propose recommendations in terms of metacognitive pedagogical methods to enhance the development of metacognition in which controlled study methods seem to be quite popular.

Figure 5 is created with the chronological keyword co-occurrence analysis. The keywords represented with darker colors were mentioned farther back in time, and in reverse, ones with lighter colored nodes were more recently used. The earliest keywords in MiME publications include problem solving, cognition, awareness and neuropsychological tests, which implies the interest of initial research in the period 2010-2020 in the relationship between metacognition and problem-solving process.

Subsequently, the more recently-mentioned keywords are mathematics, human, mail, female, humans, child and psychology, which suggests that research in the later years mainly focused on the distinction between metacognitive abilities of different subjects regarding their genders and ages. MiME research has also gained more interest since 2015-2016. The most recent keywords including "skill, arithmetic, human experiment, metacognition monitoring, academic achievement, intelligence and longitudinal study" underline the contemporary topics in this research field. It can be concluded that the aspects of metacognitions have been exploited and analyzed more and more comprehensively over time, despite the differences in research directions of each period.

DISCUSSION

This is the first study using applied bibliometric analysis and science mapping to illustrate the literature volume on MiME. After four decades, not until 2016 did the scholars publish outstanding publications on MiME. The earliest publication in the data collection was entitled: "Beyond the purely cognitive: Belief systems, social cognitions, and metacognitions as driving forces in intellectual performance" (Schoenfeld, 1983a). This study explores the impact of belief systems, interactions with social or experimental environments and skills at control level (monitoring, assessment, decision-making, and conscious metacognitive acts) on making decision and shaping humans' behavior during the problem-solving process. Metacognition in this study is examined within the role of controlling beliefs and making decisions of students in learning plane geometry via verbal methods (clinical interviews and protocol analyses). Subsequently, various research issues related to MiME has been addressed in response to **RQ3**.

Similar to other research topics, European and American scholars appear more dominant in MiME publications (Hallinger & Nguyen, 2022; Phan et al., 2022). Moreover, there are only 58 countries with publications on this topic. The most influential authors in the data collection of the very study mainly specialize in psychology instead of mathematics education. However, their research works represent "metacognition theory" and contribute greatly to MiME or 'mathematical metacognition' research. Likewise, most of the 15 most influential journals on MiME focus on psychology and social sciences, except for only two journals majoring in mathematics education.

A noteworthy finding is that ZDM, a world leading journal in mathematics education, published two volumes on Metacognition Research in Mathematics Education (volume 42, issue 2, 2010, https://link.springer.com/journal/11858/volumes-and-issues/42-2) and Metacognition in Mathematics Education (Volume 51, Issue 4, 2019, https://link.springer.com/journal/11858/volumes-and-issues/51-4). This shows the status of MiME as well as scholars' interest in MiME.

The findings of this study have some similarities as well as distinctions regarding research trends on MiME to previous studies. Similar to the conclusion of Desoete and De Craene (2019), some research directions have been appealing to scholars, including the relationship between metacognition and mathematics performance as well as metacognitive evaluation. However, while Desoete and De Craene (2019) emphasized a heightened interest in metacognitive evaluation in the extant literature, it did not appear as an outstanding research trend indicated in this study. Evidently, there are manifold opportunities and obstacles awaiting researchers concerning forms and instruments of metacognitive evaluation in the future (Desoete & De Craene, 2019; Schneider & Artelt, 2010). This discrepancy should be viewed as an open direction, a challenge for prospective researchers.

Metacognitive strategies (Dignath & Büttner, 2018; Vorhölter, 2019) and interventions on metacognition (Hacker et al., 2019; Shilo & Kramarski, 2019) are appealing research directions to researchers on psychology in mathematics education. Moreover, findings on the relationship between metacognitive skills, metacognitive strategies and academic performance, as well as the effectiveness of intervention into metacognition can vary from study to study (Desoete & De Craene, 2019). Thus, there are still opportunities for other researchers to proceed with future exploration, experiments and discoveries.

Also, metacognition, learners' genders and problem-solving capacity are topics attracting great attention among scholars. For instance, Ozcan and Eren Gumus (2019) proved that metacognitive experience is the only non-conscious structure to have a direct impact on one's mathematics problem-solving efficiency. It also acts as a mediator to deliver the influence of self-confidence on one's competence, motivations and anxiety level related to mathematics learning. The finding implies that learners' metacognitive level varies based on their genders, and mathematics metacognition regulates the relationship between academic procrastination and mathematical achievement among female students, rather than their male peers. In particular, the greater the female students' mathematics metacognition was, the less their academic procrastination could influence their mathematical achievements (Xue et al., 2023). This research direction is obviously a promising path with potential scientific discoveries in terms of the relationship between genders and metacognition and learning performance.

Early-career researchers are recommended to refer to publications of the most influential authors, the most cited publications as well as more recent documents, especially those in the two special volumes of ZDM (as mentioned above) to gain a greater insight into the development together with the latest, and most significant findings about MiME or mathematical metacognition. Moreover, novice researchers can raise their awareness of the complications and interest in the issues of MiME, which also may become their own opportunities in the future. Some suggestions for future research directions may include the relationship between metacognition and mathematics performance, interventions on metacognition, mathematical metacognition evaluation; mathematical metacognition and learners' genders and problem-solving competency.

CONCLUSIONS

In this paper, for the very first time, the scientific data about the extant literature on MiME is systematically presented. The findings reveal that metacognition publications have been on the rise in recent times, especially since 2016. Over the period of four decades, there have been 653 authors, from 58 countries publishing their publications on MiME in 162 sources. The authors from developed nations have made significant contributions to MiME research, particularly the United States, Germany, Turkey, and Belgium. Two representatives of Asia are Indonesia (at the fifth place) and China (at the ninth place) in the list of top-10 countries with the most publications on this topic.

Artzt, A. F. and Armour-Thomas, E. followed by Fias, W., de Smedt, B., Lemaire, and Patrick are ascertained as the most influential authors on MiME. The three most cited publications comprise Metcalfe and Wiebe (1987), Schoenfeld (1983a), and Veenman and Spaans (2005). It's also noteworthy that all the top cited 15 publications on MiME in the data collection of the study were published in the first phase of inadequate attention from scholars. Most of MiMe publications were published in psychological or social sciences (especially educational sciences) journals, except for only two in mathematics education-specializing journals. However, all the most influential 15 journals on MiME identified in the study are prestigious and reputable Q1 journals in the Scopus database.

The keyword co-occurrence analysis results highlight the diversified and comprehensive topics related to MiME from multiple perspectives such as adults' metacognitive ability and problem-solving capacity; metacognitive differences based on genders and ages; learners' metacognitive activities during experiential learning and mathematics concepts construction, children psychological metacognition, the emergence and chronological development of metacognition, teachability of metacognitive skills and measures for the enhancement of metacognition. Recently, researchers have been paying greater attention to metacognitive control and the role of metacognition when learning different mathematics content (mainly geometry in the past, and algebra at present), as well as the relationship between metacognition and learners' academic achievements (Abdelrahman, 2020; Fleur et al., 2021; Pradhan & Das, 2021) and intellectual capacity (Kloo et al., 2022; Wang et al., 2021).

Limitations & Recommendations

It is necessary to address the limitations of the current study in order to provide an experience lesson for following research. First and foremost, while bibliometric analysis can partly describe emerging topics and review contributions of previous studies on MiME (Pham et al., 2023), it cannot allow the researchers to conduct in-depth analysis into thematic contributions or research gaps for future studies (Wang et al., 2017). Therefore, further research is needed to overcome this limitation. Combining bibliometric analysis methods with a number of other research methods such as systematic analysis or quantitative research methods could be a solution to handle this shortcoming.

Secondly, although the Scopus database is one of the greatest scientific databases in the world, many substantial documents related to MiME are not indexed in this database (Flavell et al., 2022; Foong, 1990). It is advisable that future studies involve other databases such as Web of Sciences and Google Scholar.

Finally, within the scope of this research study, only publications in English were included in the data collection, which may leave out scientific documents in other languages (for example Schmitz et al., 2022; Sevgi & Caglikose, 2020), thereby failing to examine the research issues in non-English speaking countries. However, co-citation analysis can partly overcome this limitation by analyzing the reference lists of the publications in the data collection.

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