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Bibliometric Analysis of Mathematical Thinking Styles and Its Applications in the Field of STEM Learning

Abstract

There are many aspects that need to be studied in learning mathematics so that the practice of pedagogy in the classroom can run as expected, one of which is the students' mathematical thinking style. Studies related to this theme are seen as very interesting and also very relevant to support classroom teaching practices and developing research. The existing literature suggests that the heterogeneity of mathematical thinking styles has an impact on the difficulties of the teacher's mathematics pedagogical practice. The development of studies related to the theme of mathematical thinking style needs to be elaborated so that it becomes a reference in the continuation of studies related to this theme. Specifically, the purpose of this study is to conduct a bibliometric analysis of mathematical thinking styles, where the SCOPUS database is used as a source of document information that is reviewed and analyzed. Several document screening and analysis processes were carried out according to the purpose of the study. The first screening by entering the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles)] in all subject areas and years found 209 documents (range 1977-2022). The second screening with keywords [TITLE-ABS-KEY (mathematical AND thinking AND styles) AND (LIMIT-TO (SUBJAREA, "MATH")] in the subject area of mathematics if limited to the last 10 years, found 36 documents (time range 2012 -2022), and only 7 articles related to mathematical thinking styles were found in the article document type.Specific articles describe the importance of studies related to students' mathematical thinking styles, and differences in students' thinking styles become a big challenge for teachers' pedagogical practice in teaching mathematics. This is an important implication in this study, and teachers must find the best way to conduct mathematics learning with the differences in students' thinking styles. Finally, this study can be a reference in future studies that will explore themes related to mathematical thinking styles.

Keywords: *mathematical thinking style, bibliometric analysis, document screening, scopus*

Introduction

Learning is defined as a change in behavior through repetition and experience. These changes can come in various forms based on the individual characteristics. These characteristics include intelligence, skills, personality traits, and learning styles (Katranci & Bozkuş, 2014). On the basis of this characteristic, the diversity of students in mathematics lessons in the classroom invites us to recognize the various ways that students choose to interact with mathematical knowledge (Steinbring, 2009). When teachers invite students to solve math problems, some students may be able to identify answers from an algebraic or functional system, while other students are intent on visual or figurative answers, or others, and this may be used as this type of preference in a mathematics assessment (Huincahue et al., 2021). The diversity of these types of responses is reasonable considering the heterogeneous groups in a class, however, multiplicity often creates complex problems related to the teaching practice of mathematics teachers in the classroom. The way in which an individual prefers to present, understand and think through mathematical facts and connections with certain internal imaginations and/or external representations is referred to as mathematical thinking style (Borromeo-Ferri, 2010, 2013, 2015).

The theory of mathematical thinking style was developed by Borromeo-Ferri in 2004 based on a qualitative study of 15 and 16 year old students. In further empirical studies, which also turn into quantitative investigations, including international comparative studies (Borromeo-Ferri, 2013), the constructs of mathematical thinking styles can finally be conceptualized and operationalized. The term mathematical thinking style is based on two components of internal imagination and external representation, and the role of both (Borromeo-Ferri, 2010). The reason why mathematical thinking styles are very interesting to investigate students in learning mathematics is based on the fact that

mathematical thinking styles do not focus on performance but on individual preferences. This approach is based on Sternberg's theory of thinking style (Huincahue et al., 2021). For Sternberg, a thinking style is "a way of thinking, and it is not an ability, but a preferred way of using one's own abilities. Style refers to how a person likes to do things." In this sense, thinking style is not associated with how well something is done, but the way a person likes things to be done.

Different thinking styles are defined by Borromeo Ferri (2015), they are visual thinking style, analytical thinking style, and integrated thinking style of the two. Visual thinkers show a preference for distinctive internal pictorial imaginations and external pictorial representations as well as a preference for understanding mathematical facts and connections through holistic representations. Internal imagination is mainly influenced by strong associations with the situation experienced. Analytical thinkers show a preference for internal formal imagination and for external formal representations. Individuals are able to understand mathematical facts better through existing symbolic or verbal representations and prefer to proceed in a sequence of steps. The unified thinking style combines visual and analytical thinking and is able to switch flexibly between different representations.

Mathematical thinking style is not a mathematical ability, but a preference for how this ability is preferred to be used, and in principle mathematical thinking style is an attribute of personality, because preferences are often associated with positive influences. The study of mathematical thinking styles -to the best of our knowledge- is a rarity, in contrast to mathematical abilities or mathematical learning styles which are widely presented in previous studies (eg: Danişman & Erginer, 2017; Güneş & ahin, 2019; Kablan, 2016; Orhun, 2007; Tatar & Dikici, 2009, and many other studies). Therefore, our current study is to carry out a bibliometric analysis of mathematical thinking styles. This study is expected to be a reference in several further research modes related to mathematical thinking styles.

Method

Specifically, the purpose of this study is to conduct a bibliometric analysis of mathematical thinking styles. This study is related to a coherent literature study with the theme "mathematical thinking style" in popular terms today known as bibliometric analysis study (BAS) or bibliometric analysis studies, or more familiarly referred to as bibliometric analysis. meta-analysis studies. Our bibliometric analysis study (BAS) was adapted from Wirzal et al. (2022), where the SCOPUS database is used as a source of document information that is reviewed and analyzed. Several document screening and analysis processes were carried out according to the purpose of the study.

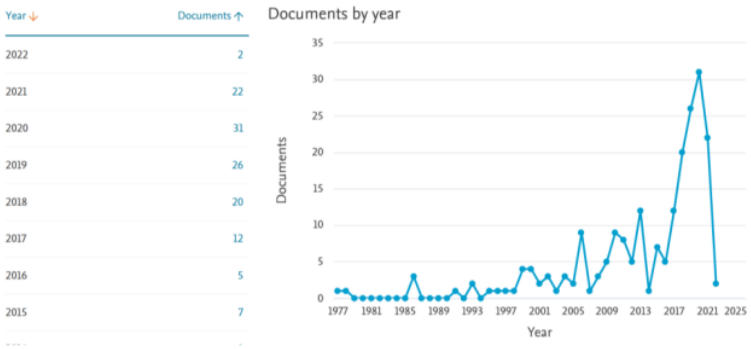
The SCOPUS database with the page (https://www.scopus.com/) is used as a source of information for the analyzed documents. The main consideration is that SCOPUS is recognized as an indexer of scientific works of books or journals with a high reputation and is recognized by the world community, this is mainly because the data source presented is very accurate, so it can be used as a benchmark for measuring the quality of articles in a publisher. In addition, the full features presented on the SCOPUS page allow each individual to explore each quality and complete manuscript by title, author, publisher, metric data, citations, quartiles, and others in detail, accurately, and comprehensively.

Bibliometric analysis study was conducted on May 24, 2022 by exploring the SCOPUS database on the website (https://www.scopus.com/search). In the document search menu or "search documents" keywords are entered with the theme of the study of mathematical thinking styles, and these are inserted in English "mathematical thinking style" so that they can be adequately explored and read on the SCOPUS page. Document screening is done twice, the first by entering the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles)] where there is no year limit on the document search

including no subject area limitation, and the second with the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles) AND (LIMIT-TO (SUBJAREA, "MATH")] where this study limits the documents in the last 10 years and is specific to the subject area of mathematics. Each searching results from the documents displayed on the page SCOPUS is then documented and displayed. Each data visualized by SCOPUS is then printed (print screen) and analyzed descriptively, and discussed as needed in this study.

Results and Discussion

The first screening of documents by entering the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles)]. It should be noted that in the first screening we did not limit the year the document was searched including did not limit the subject area. Based on these criteria, 209 documents were found in the period 1977-2022 (no documents were found before 1977). The search results (distribution) of documents by year are presented in Figure 1.



Year	Documents
2022	2
2021	22
2020	31
2019	26
2018	20
2017	12
2016	5
2015	7

Figure 1. Results of searching with the keyword 'Mathematical Thinking Styles' TITLE-ABS-KEY (mathematical AND thinking AND styles)

The trend of studies related to Mathematical Thinking Styles has increased relatively since the first document in 1977 until now. The peak was in 2020 where 31 documents related to the discussion of mathematical thinking styles were detected. The most surprising finding of this study is that Indonesia is the country that contributes the most documents by territory or country related to mathematical thinking styles (see Figure 2).

Country/Territory	Documents
Indonesia	49
United States	37
Russian Federation	19
China	14
Germany	11
United Kingdom	11
Japan	6
Italy	5
Malaysia	4

Figure 2. Document search results based on territory or country related to mathematical thinking style

Figure 2 shows the results of document searches based on territory or country related to mathematical thinking styles. The top five proportions of countries with the most intent on writing with a number of study documents related to mathematical thinking styles, respectively are Indonesia with 49 documents, USA with 37 documents, Russia with 19 documents, China with 14 documents, Germany and UK each with 11 documents, and the rest under 10 documents.

The findings in Figure 2 suggest that Indonesian scholars are the most intensive in conducting studies on mathematical thinking styles. As an assumption, this may be because Indonesia still has many problems related to learning, mathematics, thinking styles, and the three aspects that are intensively investigated. However, this is an assumption, because the initial screening in this study did not carry out a detailed review of the aspects studied from 49 documents originating from Indonesia. Furthermore, detailed data based on document type and subject area are presented in Figure 3.

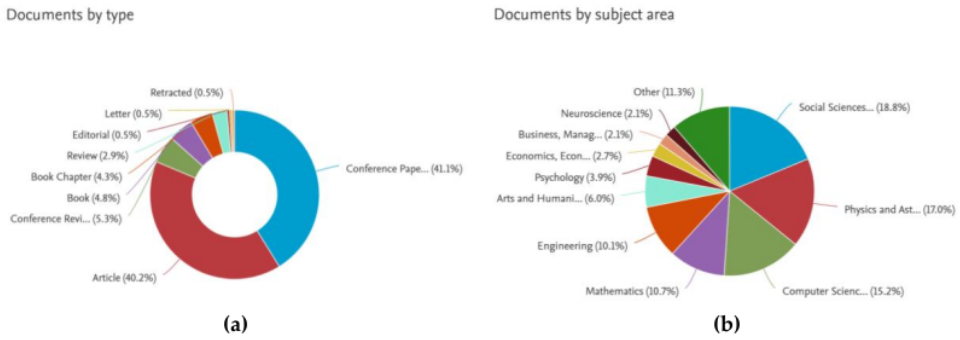


Figure 3. Detailed data based on; (a) document type, and (b) subject area

The results in Figure 3a indicate that the types of documents are spread over nine types, including: conference papers as many as 86 documents (41.1%), journal articles as many as 84 (40.2%), conference reviews as many as 11 documents (5.3%), books and book chapters respectively. respectively as many as 10 documents (4.8%) and 9 documents (4.3%), and other types of documents under 3%. Meanwhile, the distribution of documents for subject areas (Figure 3b) was identified in many areas, ranging from social science, physics and astronomy, computer science, mathematics, engineering, and others. The number of documents in the social science subject area is 63 documents (18.8%), physics and astronomy are 57 documents (17%), computer science is 51 documents (15.2%), mathematics is 36 documents (10.7%), engineering is 34 documents (10.1%), and others are under 10%, including those studying in the area of psychology (3.9%).

Next, the second document screening is carried out. If it is specific to the subject area of mathematics with the keywords [TITLE-ABS-KEY (mathematical AND thinking AND styles) AND (LIMIT-TO (SUBJAREA, "MATH")], 36 documents were found, their distribution is presented in Figure 4.

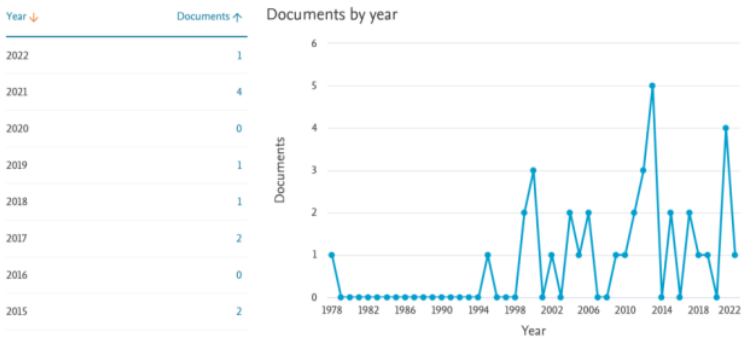


Figure 4. Result of searching with keywords [TITLE-ABS-KEY (mathematical AND thinking AND styles) AND (LIMIT-TO (SUBJAREA, "MATH"))]

The results of the second screening in Figure 4 are specific to the subject area of mathematics. The trend of the number of documents in the range from 1977 to 2022 fluctuated, but the most notable was in 2013 and 2021, the number of documents found was 5 and 6 documents, respectively. Distribution of documents by type of the 36 documents screened were articles with 19 documents (52.8%), conference papers with 8 documents (22.2%), books and book chapters with 4 documents (11.1%), and 1 review document (2.8%).

Screening with the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles) AND (LIMIT-TO (SUBJAREA, "MATH"))] and is limited to the year of the document, namely in the last 10 years (2012 to 2022), then the results are presented in Figure 5.

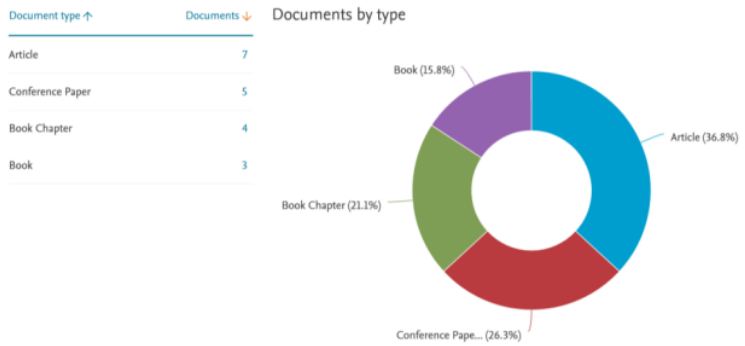


Figure 5. Search results using the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles) AND (LIMIT-TO (SUBJAREA, "MATH"))], and the document year range is limited to 2012 to 2022

Furthermore, if the document is specified in one type, namely articles, there are found as many as 7 article documents (36.8%) that discuss mathematical thinking styles or the relationship between these three variables in a specific subject area, namely mathematics, and this is in the last 10 years. These documents are presented in Table 1.

Table 1. Document details related to mathematical thinking style with document type 'article' in the last 10 years.

Nu	Short Title	Author and Year	Journal Source
1	The optimal solution of feature …..	(Hu et al., 2022)	App. Math. Nonlin. Sci.
2	Discourses as the place for the development …..	(Schütte et al., 2021)	J. Math. – Did.
3	Impediments to mathematical creativity …..	(Haavold, 2021)	Math. Enth.
4	The potential of recreational mathematics …..	(Rowlett et al., 2019)	Intl. J. of Math. Edu. in Sci. Tech.
5	Using activity theory to model …..	(Huang & Lin, 2013)	Intl. J. of Sci. Math. Edu.
6	Computational phenotyping of two-person …..	(Xiang et al., 2012)	PLoS Comp. Bio.
7	Thinking styles of mathematics …..	(Spangenberg, 2012)	Pythagoras

In accordance with the theme of the study being screened, the first article relates the existing operating modes based on the concept of nonlinear thinking (Hu et al., 2022). The second article discusses learning mathematics from an interactionist perspective. Aspects of developing mathematical thinking are discussed. Based on the interactionist perception of learning the development of mathematical thinking is described as increased participation in mathematical discourse. In this article's empirical analysis, different styles of discourse are reconstructed, which we call narrative, formal and 'narrative' discourse. In future work, it will be used as a theoretical basis for the longitudinal reconstruction of learners' participation in the mathematical negotiation process to describe the development of their mathematical thinking (Schütte et al., 2021).

The third article alludes to mathematical techniques in proof writing which can be narrowed down to a particular style of proof. Discussed the skills and mathematical thinking styles involved in writing proof of mathematical statements (Haavold, 2021). The fourth article deals with the need for mathematical thinking or skills in learning that can be used effectively to motivate engagement with and develop an understanding of mathematical ideas or concepts (Rowlett et al., 2019). The fifth article is related to learning mathematics from a sociocultural perspective, holistic and analytical thinking styles presented in teaching materials and teaching activities are investigated in influencing students' understanding of mathematical concepts (Huang & Lin, 2013).

The sixth article is related to the computational system for predicting the depth of thinking of the subject (Xiang et al., 2012). Although the sixth article fits the criteria according to the specified keywords, it does not specifically relate it to learning mathematics and does not specifically talk about mathematical thinking styles. Finally, the seventh article relates to studies to characterize and compare students' thinking styles in learning mathematics, where each student's thinking style is different and becomes a challenge for teachers in learning mathematics with different students' thinking styles (Spangenberg, 2012).

Finally, refer to articles in the last 10 years discussing mathematical thinking styles, especially very specific related studies (study from: Haavold, 2021; Huang & Lin, 2013; Rowlett et al., 2019; Schütte et al., 2021; Spangenberg, 2012) can contribute to further studies, and it is clear that the differences in

students' thinking styles pose a major challenge to teachers' pedagogical practice in teaching mathematics. This is an important implication in this study, and teachers must find the best way to conduct mathematics learning in the light of students' different thinking styles.

Conclusion

A bibliometric analysis study on mathematical thinking styles has been carried out using the SCOPUS database as a source of information. Document screening has been carried out, the first screening by entering the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles)] in all subject areas and year found as many as 209 documents (range 1977-2022). The second screening with keywords [TITLE-ABS-KEY (mathematical AND thinking AND styles) AND (LIMIT-TO (SUBJAREA, "MATH")] in the subject area of mathematics if limited to the last 10 years, found 36 documents (time range 2012 -2022), and only 7 articles related to mathematical thinking styles were found in the article document type.Specific articles describe the importance of studies related to students' mathematical thinking styles, and differences in students' thinking styles become a big challenge for teachers' pedagogical practice in teaching mathematics. This is an important implication in this study, and teachers must find the best way to conduct mathematics learning with the differences in students' thinking styles. Finally, this study can be a reference in future studies that will explore themes related to mathematical thinking styles.

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