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Mathematical Thinking Styles and Its Implications in Science Learning: A Bibliometric Analysis

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Abstract: Mathematical thinking style is an aspect that needs to be studied, especially its implications for the practice of science pedagogy in the classroom, considering the role of mathematics in science learning is very important. Studies related to this theme are seen as very interesting and also very relevant to support future teaching and research practices. The purpose of this study is to conduct a bibliometric analysis of mathematical thinking styles and their implications in science learning. Specifically, this bibliometric study aims to describe and examine literature in areas that are coherent with the concept of mathematical thinking style, and coherence between mathematical thinking style and science learning. The SCOPUS database is used as a source of document information. Screening and document analysis were carried out according to the keywords inserted in the 'search document' menu. With several modes of screening documents in areas that are coherent with the concept of mathematical thinking style and its implications in science learning, a number of documents were found that examine the subject area. The specific screening steps and document findings are discussed further in this article. Basically, specific articles that are coherent with the theme of bibliometric analysis 'mathematical thinking styles and their implications in learning science' describe the importance of studies related to students' mathematical thinking styles. Differences in students' thinking styles become a big challenge for teachers' pedagogical practices in teaching mathematics and science. This is an important implication in this study, and teachers must find the best way to conduct mathematics and science learning in the light of the different mathematical thinking styles of students. Finally, this study can be a reference in future studies that will explore themes related to mathematical thinking styles.

Keywords: Mathematical thinking style; Science learning; Bibliometric analysis

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Introduction

Learning is defined as a change in behavior through repetition and experience. These changes can come in a variety of forms based on 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 classroom learning invites us to recognize the various ways that students choose to interact with a particular area of knowledge (Steinbring, 2009). When the teacher invites students to solve problems related to mathematical contexts, 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 a type of preference in an assessment (Huincahue et al., 2021).

The diversity of responses in students' ways of thinking is reasonable, considering the very heterogeneous groups in a class, it's just that multiplicity often creates complex problems related to teacher teaching practices in the classroom. The way in which an individual prefers to present, understand and think

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through mathematical facts and connections with certain internal imagination and/or external representations is referred to as mathematical thinking style (Borromeo-Ferri, 2010, 2013, 2015).

The implications of the importance of thinking styles are often associated with experiences and learning outcomes in STEM (Science, Technology, Engineering and Mathematics) education. For example, STEM learning attitudes are associated with thinking styles (Sirakaya et al., 2020). In a more intensive study is the involvement of mathematical thinking frameworks related to STEM learning (Miller, 2019). Aspects of mathematical modeling are also discussed as a bridge (bridging) in STEM education, in the context of its role in providing opportunities for teaching ways to support creativity, acquire new skills, bring innovation, and many other impacts on student development (Tezer, 2020). The study by Khalifaeva et al. (2020) found a relationship between thinking styles and student learning achievement. One aspect of STEM is science, and there are research findings that show changes in students' thinking styles that depend on each stage of physics science learning applied by the teacher (Utami et al., 2021). For this role, mathematical thinking style is seen as having implications in the field of STEM learning, especially science. In addition, between mathematics and science are two studies whose existence cannot be separated from each other, and both support each other (Evendi & Verawati, 2021).

The theory of mathematical thinking style was originally developed by Borromeo-Ferri in 2004, it is based on a qualitative study conducted on students aged fifteen and sixteen. In the empirical studies that have been carried out, which then turned into quantitative studies (Borromeo-Ferri, 2013), in the end the construct of mathematical thinking style can be conceptualized and until now operationalized in the field of learning. Aspects of internal imagination and external representation, as well as the role of both are fundamental components of mathematical thinking style (Borromeo-Ferri, 2010).

The fact that mathematical thinking style is not focused on individual performance but related to their preferences, and this is one of the reasons why mathematical thinking style is very interesting to investigate students in learning mathematics. Sternberg's theory of thinking styles (in Huincahue et al., 2021) states that a thinking style is a 'way of thinking' (not an aspect of thinking ability), but the preferred way by individuals to use their abilities, or in other words 'a style that refers to on how individuals like to do things.' This is the basis of the development of a mathematical thinking style approach. In a more specific sense, thinking style is ultimately not associated with how well something is done, but the way individuals like things to be done (Huincahue et al., 2021).

Different thinking styles are defined by Borromeo-Ferri (2015), they are analytical thinking style, visual thinking style, and integrated thinking style (visual-analytical). 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. 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. 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.

Our current study is to conduct a bibliometric analysis of mathematical thinking styles and their implications for the field of science learning. Specifically, this bibliometric study aims to describe and examine literature in areas that are coherent with the concept of mathematical thinking style, and coherence between mathematical thinking style and science learning. This study is expected to be a reference in several further research modes related to mathematical thinking styles and their implications in the field of science learning.

Method

Specifically, the purpose of this study is to conduct a bibliometric analysis of mathematical thinking styles and their implications for the field of science learning. This study is related to a coherent literature study with the theme 'mathematical thinking style and its implications for the field of science learning' in terms that are currently popularly known as bibliometric analysis study (BAS), or often referred to as 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 (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 24-May 2022 by exploring the SCOPUS database on the website (https://www.scopus.com/search). Focusing on the first objective, bibliometric analysis in areas that are coherent with the concept of mathematical thinking style. The steps taken are: (a) In the 'search documents' menu, the keyword 'mathematical thinking style' is entered, so that it can be adequately explored and read on the SCOPUS page; (b) Document screening was carried out twice, the first by entering the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles)], where there was no year limit on the document search and 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 documents to the last 10 years and is specific to the subject area of mathematics; (c) Each searching result from the document displayed on the SCOPUS page is then documented and displayed; (d) Each data visualized by SCOPUS is then printed (print screen) and analyzed descriptively, and discussed as needed in this study.

Furthermore, the focus on the second goal is bibliometric analysis in a coherent area between mathematical thinking style and science learning, then the steps taken are: (a) In the 'search documents' menu, the keyword 'mathematical thinking style in science learning' is entered so that it can be adequately explored and read on the SCOPUS page; (b) Document screening is done by entering the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles AND science AND learning)], where there is no year limit on document search and no subject area limit; (c) Each searching result from the document displayed on the SCOPUS page is then documented and displayed; (d) Each data visualized by SCOPUS is then printed (print screen) and analyzed descriptively, and discussed as needed in this study.

Result and Discussion

The first document screening 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.

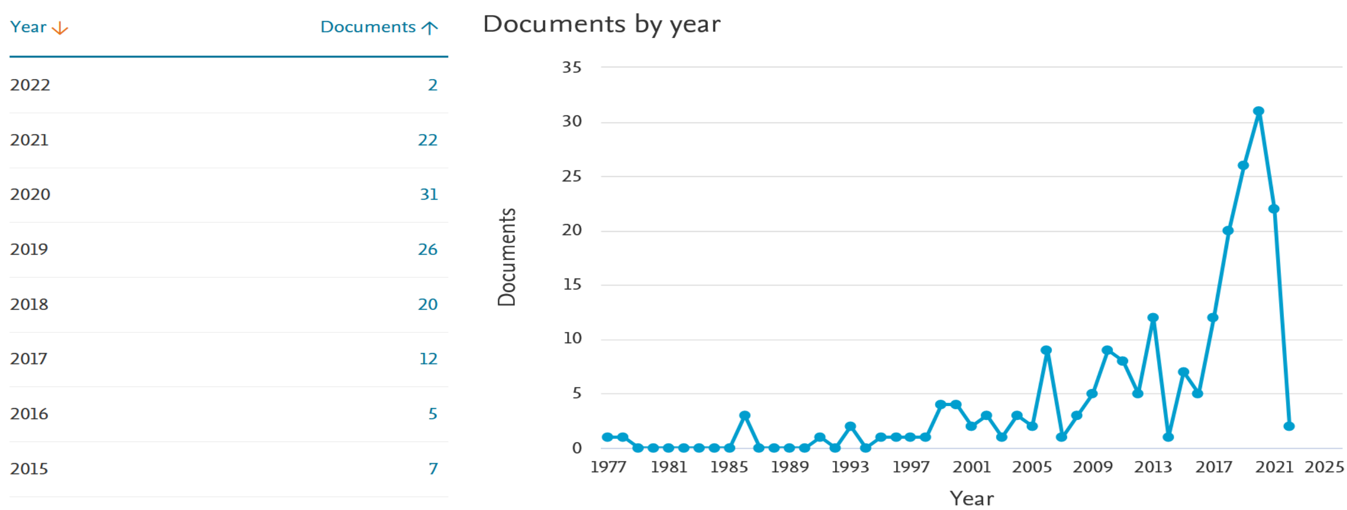


Figure 1. Results of searching with the keyword 'mathematical thinking styles'

The trend of studies related to mathematical thinking styles has relatively increased 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).

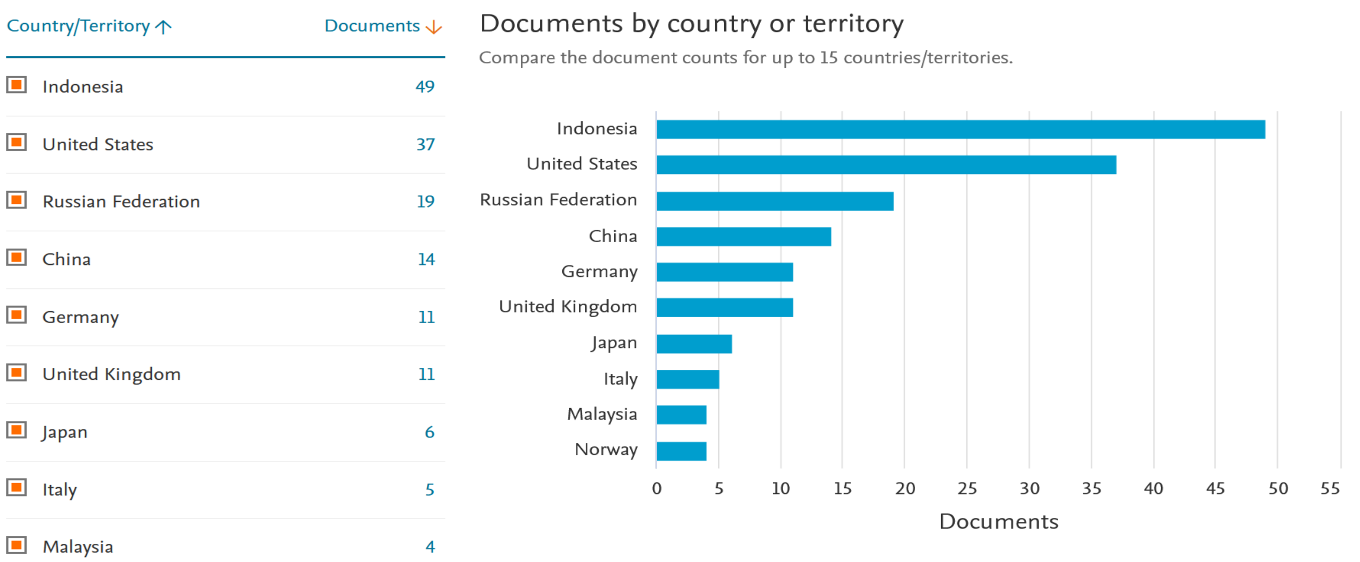
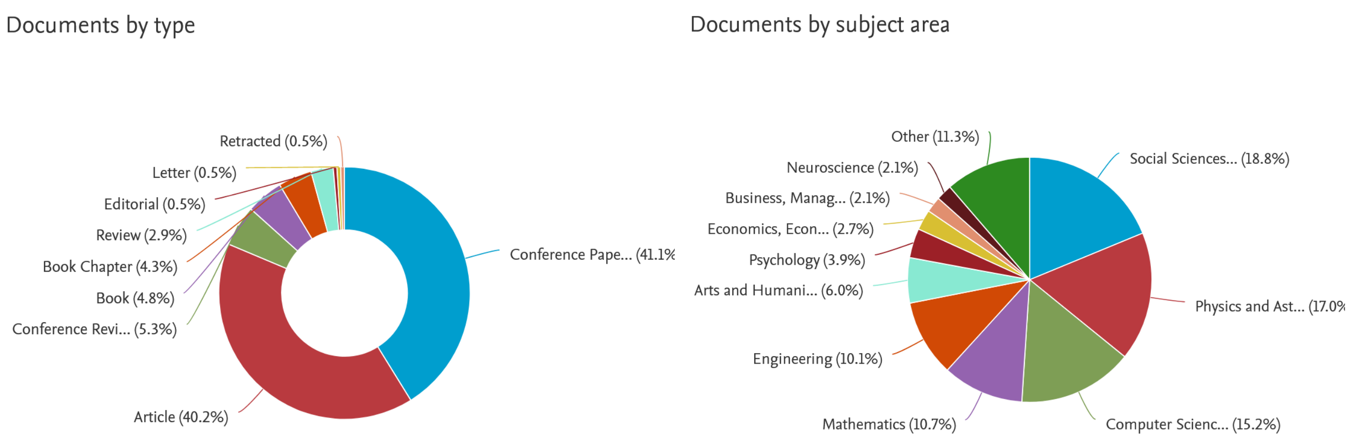


Figure 2. Document search results based on territory or country related to mathematical thinking style

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.



(a) **(b)**

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 who study 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, the distribution is presented in Figure 4.

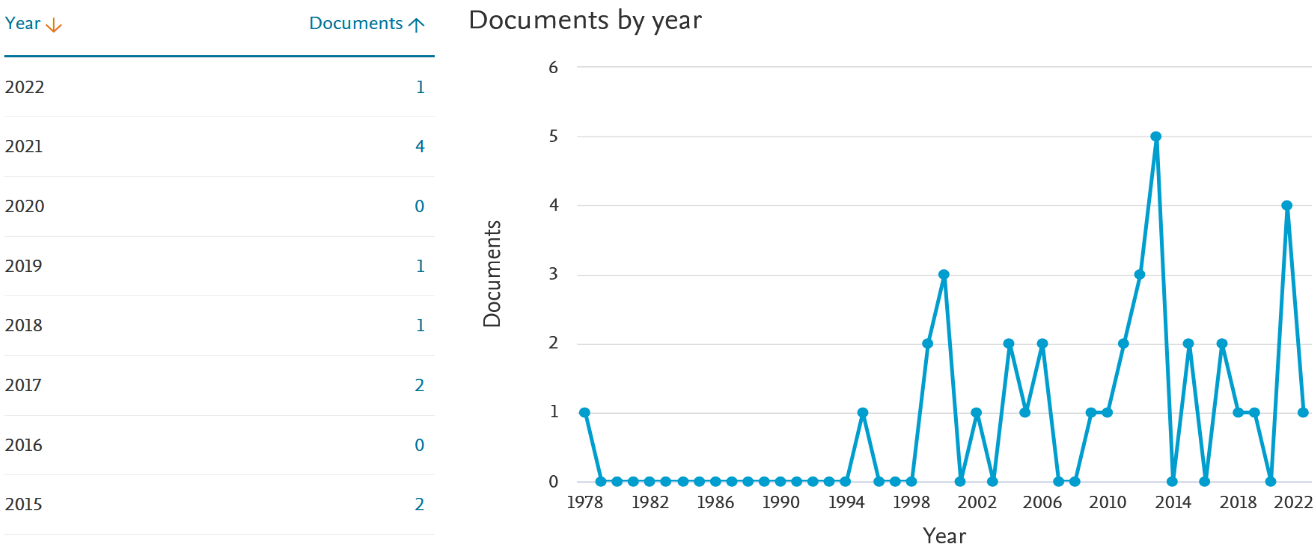


Figure 4. Search results with keyword 'mathematical thinking styles,' subject area of 'math'

The results of the second screening in Figure 4 are specific to the subject area of mathematics. The trend in the number of documents from 1977 to 2022 was fluctuating, but the most prominent was in 2013 and 2021, where 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 each 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.

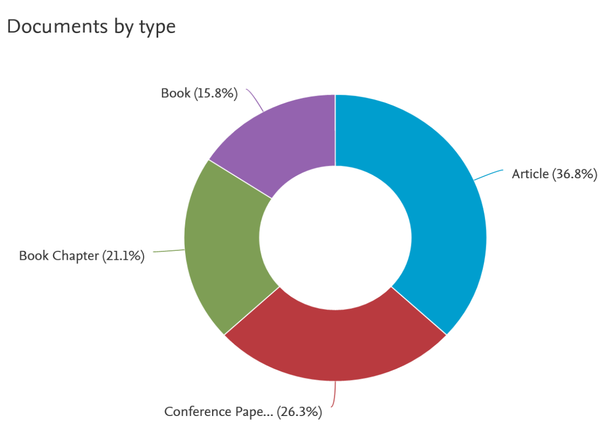


Figure 5. Results of searching documents in the subject area of mathematics in the last 10 years

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. Details of documents related to mathematical thinking style with document type 'article' in the last 10 years.

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

In accordance with the theme of the study being screened, the article based on the study by Hu et al.

(2022) relate the operating mode based on the concept of nonlinear thinking (does not discuss thinking styles explicitly). The study by Schütte et al. (2021) discusses mathematics learning from an interactionist perspective, where the development of mathematical thinking is described as increased participation in mathematical discourse. In the empirical analysis of this article, different discourse styles are reconstructed and can be used as a theoretical basis for the longitudinal reconstruction of students' participation in the mathematical negotiation process to describe the development of their mathematical thinking.

The study by Haavold (2021) alludes to mathematical techniques in writing proofs that can be narrowed down to a particular style of proof. Mathematical thinking skills and styles are both involved in writing proofs of mathematical statements. The article written by Rowlett et al. (2019) is related to the need for thinking or mathematical skills in learning that can be used effectively to motivate student engagement by developing an understanding of mathematical ideas or concepts. The article written based on the results of a study by Huang & Lin (2013) shows that the holistic and analytical thinking styles presented in teaching materials and teaching activities can have an impact on students' understanding of mathematical concepts.

The article written by Xiang et al. (2012) related to a computational system to predict the depth of thinking of the subject. Although this article falls into 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 article from Spangenberg (2012), relates to a study 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.

Focusing on bibliometric analysis on a coherent area between mathematical thinking style and science learning, the trend of studies based on document search results (documents by year) is presented in Figure 6. This includes the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles) AND science AND learning)] on the menu searching document.

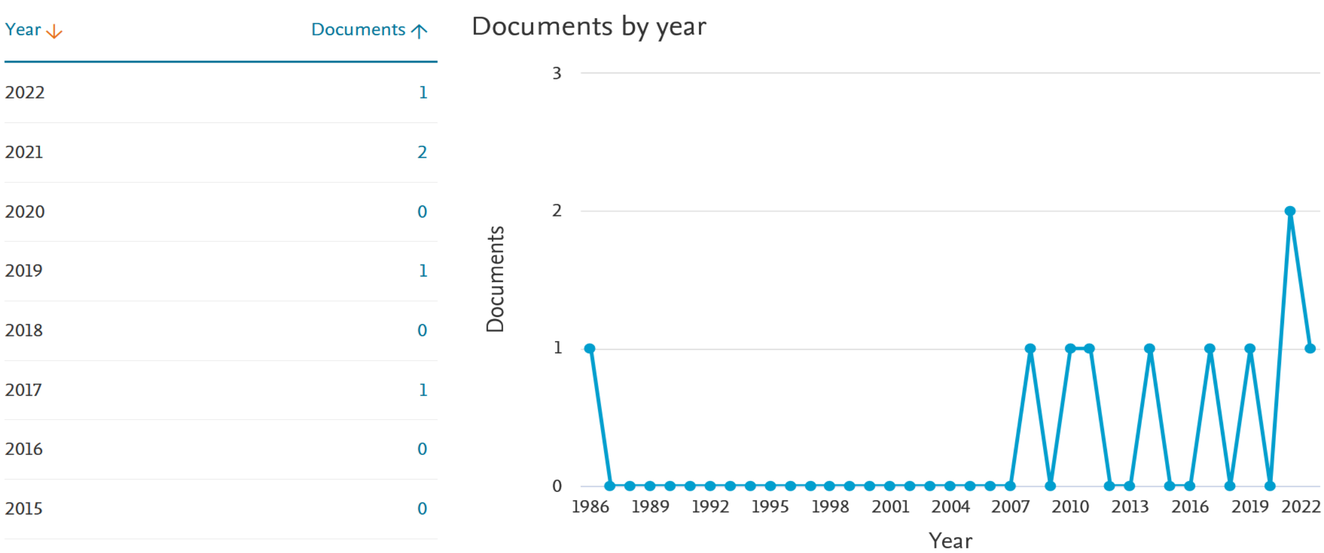


Figure 6. Results of searching with the keyword 'mathematical thinking styles in science learning'

The results in Figure 6 show the trend of studies in the area of 'mathematical thinking styles in science learning,' where there is no year limit for document searches and no subject area limitation. In this search mode, 10 documents were found in the range from 1986 to 2022. This number is quantitatively very small, meaning that there are still few studies linking mathematical thinking styles with learning science. As a side note, this is based on a document based on SCOPUS.

With the same keywords, the document type of the data presented by SCOPUS is as shown in Figure 7.

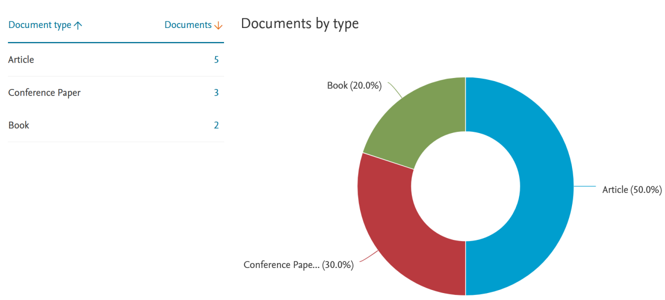


Figure 7. Detailed data by document type

Ten documents resulting from searching are distributed into three types, they are articles with 5 documents (50%), conference papers with 3 documents (30%), and books with 2 documents (20%). Details of documents related to mathematical thinking styles in science learning are presented in Table 2.

Table 2. Details of documents related to mathematical thinking styles in science learning

Title Abbreviation	Author (s) & Year	Source
The implementation of STEM learning ….	(Utami et al., 2021)	AIP Conf. Proc.
Situated Learning with Bebras ….	(Bellettini et al., 2019)	Lec. Not. in Comp. Sci.
The educational prospects of ….	(Vasileva-Stojanovska et al., 2014)	Proc. of the Europ. Conf.
Quantification of Learning Gains in a Science ….	(Keating et al., 2022)	FASEB J.
Cognitive style and specific-purpose course design ….	(Flowerdew, 1986)	Eng. for Spec. Purp.
Constructionist co-design: A dual approach ….	(Kelter et al., 2021)	Brit. J. of Edu. Tech.
STEAMing the ships for the ….	(Shih et al., 2017)	Int. Des. and Arc.
Mathematically gifted children: Developmental ….	(O'Boyle, 2008)	Roep. Rev.
The shape of algebra in the mirrors ….	(Katz & Nodelman, 2011)	Book
Differentiating for the young child ….	(Smutny, 2022)	Book

From the ten articles presented in Table 2, there is one article that specifically relates science (physics) to thinking styles, namely the study conducted by Utami et al. (2021). The findings in the study show that changes in students' thinking styles depend on each stage of learning physics applied by the teacher (Utami et al., 2021).

Another finding in the mode of teaching science, or social science in general is that individual preferences (eg, learning styles) become one of the important factors in personalized learning for better learning outcomes (Vasileva-Stojanovska et al., 2014). Furthermore, in research on cognitive neuroscience by O'Boyle (2008) recommends that instructional techniques should be developed by teachers by utilizing the tendency of mathematics learning styles in each student, this will facilitate teachers in the appropriate learning flow in learning mathematics and science.

Finally, referring to articles discussing mathematical thinking styles (study from: Haavold, 2021; Huang & Lin, 2013; Rowlett et al., 2019; Schütte et al., 2021; Spangenberg, 2012), can contribute to a wealth of literature for the subsequent studies, and it is very clear that the differences in students' thinking styles become a major challenge to the teacher's pedagogical practice in teaching mathematics. Likewise, findings that discuss mathematical thinking styles in science learning (for example, studies by O'Boyle, 2008; Utami et al., 2021; Vasileva-Stojanovska et al., 2014), their findings imply that instructional techniques should be developed by utilizing tendency of mathematics learning style which can be a reference for science learning. This is also an important implication in current bibliometric studies, that teachers must find the best way to conduct learning (mathematics and science) with the differences in students' mathematical thinking styles.

Conclusion

A bibliometric analysis study on 'mathematical thinking styles and their implications in science learning' has been carried out using the SCOPUS database as a source of information. Objectives in areas that are coherent with the concept of mathematical thinking style are carried out by several screening steps. The first screening was by entering the keyword [TITLE-ABS-KEY (mathematical AND thinking AND styles)] in all subject areas and years, which found 209 documents (year range from 1977 to 2022). The second screening was using the keywords [TITLE-ABS-KEY (mathematical AND thinking AND styles) AND (LIMIT-TO (SUBJAREA, 'MATH')] in the mathematics subject area, and if limited to the last 10 years, 36 documents were found (year range from 2012 to 2022), and in the article document type, only 7 articles were found related to mathematical thinking styles (in the mathematics subject area, the document type was articles).

The aim of a coherent area between mathematical thinking style and science learning is carried out by screening on specific keywords: 'mathematical thinking styles in science learning' [TITLE-ABS-KEY (mathematical AND thinking AND styles AND science AND learning)], searching involves all subject area and year. As a result, 10 documents were found between 1986 and 2022. These were distributed into three types of documents: articles, conference papers, and books.

Specific articles that are coherent with the theme of bibliometric analysis 'mathematical thinking styles and their implications in science learning' describe the importance of studies related to students' mathematical thinking styles. Differences in students' thinking styles become a big challenge for teachers' pedagogical practices in teaching mathematics and science. This is an important implication in this study, and teachers must find the best way to conduct mathematics and science learning in the light of the different mathematical thinking styles of students. Finally, this study can be a reference in future studies that will explore themes related to mathematical thinking styles.

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