Higher-order thinking research in mathematics education: a bibliometric mapping analysis

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ABSTRACT

This study presents a bibliometric analysis of research on higher-order thinking skills (HOTS) in mathematics education. The objectives are to examine publication distribution and identify leading journals, authors, institutions, and countries. Data were retrieved from the Scopus database and analyzed using VOSviewer software. A total of 104 articles published between 2004 and 2022 were reviewed. Various visual representations, including graphs, tables, charts, and maps, were used to present the findings. The results show that HOTS research in mathematics education is closely associated with problem-solving, mathematics learning, and assessment. Eurasia Journal of Mathematics, Science, and Technology Education emerged as the most prominent journal, while Universiti Teknologi Malaysia was identified as the most influential institution, with Malaysia playing a significant role in this research domain. These findings provide a comprehensive overview of the research landscape and offer directions for future studies in mathematics education. Based on these results, suggestions for future research are proposed.

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1. INTRODUCTION

Higher-order thinking skills (HOTS) play a vital role in equipping individuals to meet 21st-century challenges [1], [2]. These skills support critical and creative thinking and remain increasingly important for future educational and professional demands [3]. Within the scientific domain, HOTS are formally recognized as integrating conceptual knowledge, procedural understanding, and metacognitive abilities [4]. HOTS extends beyond simple fact recall or replicating prior examples; it demands advanced cognitive processing, the ability to handle complex situations, non-algorithmic reasoning, problem-solving proficiency, and the capacity to devise multiple solutions [5].

Enhancing HOTS contributes to improved cognitive abilities, skills, and values, allowing individuals to apply their knowledge effectively in problem-solving and decision-making [6]. In mathematics, students with a solid conceptual understanding tend to demonstrate HOTS when engaging in analysis, evaluation, and creation [7]. Therefore, fostering HOTS is essential for developing critical thinking, creative problem-solving, and informed decision-making [8]. Moreover, HOTS play a key role in mathematics education [9]–[13], as they not only help students tackle complex problems but also promote critical and creative thinking, decision-making, problem-solving, communication, and collaboration [14], [15].

Researchers and educational experts have highlighted the significance of HOTS in mathematics education [16], [17], emphasizing the need for students to go beyond basic computations and rote memorization of formulas [18]. The effectiveness of mathematics instruction and the quality of teaching materials play a crucial role in developing students' HOTS [19]. HOTS is not merely about acquiring knowledge; it involves organizing, connecting, and critically assessing information to achieve specific goals [20], [21]. It encompasses various mathematical thinking skills, including reasoning, analysis, evaluation, creativity, organization, systematic and complex thinking, as well as both critical and creative thought processes [17]. Additionally, HOTS requires students to interpret, examine, and manipulate information effectively [22].

Given the essential role of HOTS in mathematics education, numerous research articles on this subject have been published in academic journals. These publications provide valuable insights and data that can support further studies through systematic reviews, content analysis, and bibliometric assessments. This study employed bibliometric analysis to examine and interpret the bibliometric data of scholarly papers focused on higher-order thinking in mathematics education.

Bibliometrics is a quantitative method used to analyze author contributions and citation patterns within a research field over time, providing insights into its development and trends [23]. Basic bibliometric analysis employs descriptive statistics to map key trends within a body of knowledge [24], helping to assess research impact, identify areas of interest, and reveal underlying connections [25]. Additionally, it aids in evaluating the most influential studies, themes, researchers, institutions, and journals in a specific field. Despite its utility, bibliometric analysis has been infrequently applied in mathematics education research [26]. While previous studies have examined the bibliometrics of higher-order thinking in physics [27], they have not specifically addressed its application in mathematics education. Therefore, this bibliometric study aims to explore the landscape of higher-order thinking research in mathematics education by identifying current trends, dominant themes, and key scholarly contributions. Furthermore, it provides a broad overview of existing literature while offering insights into future research directions in this field. This study addresses the following research questions:
- Which countries demonstrate the strongest international collaborations in HOTS research in mathematics education?
- Which journals, authors, and articles are the most influential in this field?
- What are the dominant themes and emerging trends based on keyword analysis?

In the revised Bloom's taxonomy, cognitive skills are categorized into two main levels: HOTS and lower-order thinking skills (LOTS) [11], [14], [28]–[30]. HOTS includes the top three cognitive domains namely: analyzing, evaluating, and creating, while LOTS comprises remembering, understanding, and applying. The key indicators for each stage are as follows: i) remembering involves retrieving knowledge from long-term memory through recognition and recall; ii) understanding refers to constructing meaning from learning experiences, including interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining; iii) applying entails using acquired knowledge in practical contexts by executing or implementing procedures; iv) analyzing requires breaking down information into components and identifying relationships within a structure (differentiating, organizing, attributing); v) evaluating involves making judgments based on established criteria (checking, critiquing); and vi) creating focuses on synthesizing elements to generate new ideas, structures, or solutions (generating, planning, producing) [29].

Furthermore, Abdullah *et al.* [31] categorizes HOTS into three main domains: problem-solving, critical thinking, and creativity. Problem-solving entails recognizing issues, gathering relevant information, analyzing it, and selecting appropriate solutions [32], [33]. Critical thinking involves objectively evaluating information, applying logical reasoning, and forming well-supported conclusions. Meanwhile, creativity focuses on generating novel ideas, refining existing concepts, and innovating new methodologies by analyzing and assessing prior knowledge.

2. METHOD

In this study, a bibliometric analysis method is used to investigate literature related to the research on higher-order thinking in mathematics education. Citation analysis was used to identify influential articles, authors, institutions, and countries. Co-occurrence and co-citation analyses were conducted to examine themes and intellectual structure. Our goal is to find the most influential papers, authors and universities related to higher-order thinking research in mathematics education through citation analysis. The co-occurrence analysis identifies which themes have a greater impact on research, while the co-citation analysis reveals the knowledge base of research and its intellectual structure. The overall procedures of the current study are described in Figure 1.

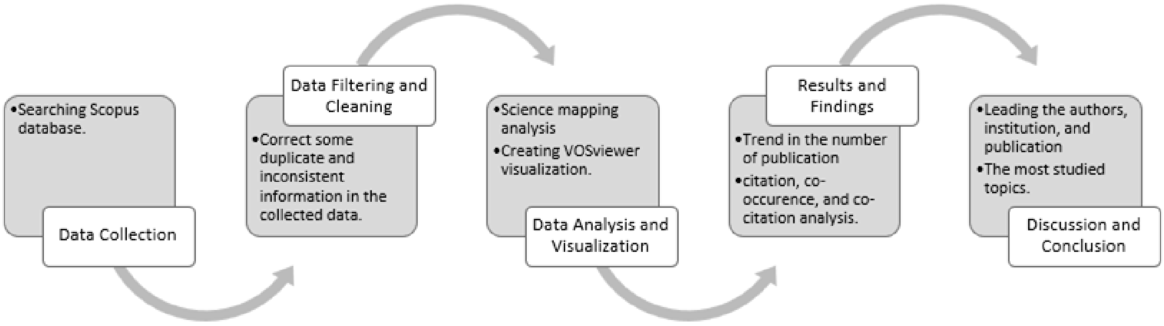

Figure 1. The workflow of the current research study

2.1. Data collection

The bibliometric data were retrieved from the Scopus bibliometric database. In this study, the Scopus database was chosen because it covers a much wider range of materials compared to other databases (70% more sources compared to the Web of Sciences (WoS)) [34], [35]. The authors search the Scopus database (http://www.scopus.com) using the term 'higher order thinking' or 'higher-order thinking' with the central theme 'mathematics education'. Keyword search was limited to the presence of the search term in the titles, abstracts, and keywords of the articles, using advanced search options to enter search terms and syntactically match search engine operators. The type of documents was limited to articles written in English. We also limited our search to documents published from 2002 onward. The starting year of the search was selected based on the publication of the revised Bloom's taxonomy by Anderson and Krathwohl in 2001 [29], which served as a conceptual foundation for this study. Consequently, 138 documents were retrieved. The summary of the criteria for the selection of publications is shown in Table 1.

Table 1. Summary of the criteria for selecting publications

Criteria	Value
Data source	Scopus
Search terms	("higher order thinking" OR "higher-order thinking") AND (mathematics AND (edu* OR learn* OR teach* OR train* OR student* OR pedagogy OR curricul*)
Publication periods	2002 to 2022
Source type	Journal
Document type	Article
Language	English

2.2. Data filtering and cleaning

The authors refined the dataset by screening titles, abstracts, and keywords to ensure relevance. Articles unrelated to higher-order thinking in mathematics education, such as those focusing on science teacher education, physics, chemistry, biology, science, technology, engineering and mathematics (STEM), and science, technology, engineering, art, mathematics (STEAM) were excluded, along with those not aligning with the research objectives. Additionally, inconsistencies in author names, source titles, and institutional affiliations were corrected. For instance, ZDM-International Journal on Mathematics Education and ZDM-Mathematics Education were merged under a single source title, while institutions such as Universiti Kebangsaan Malaysia and National University of Malaysia were standardized. Similarly, Yogyakarta State University and Universitas Negeri Yogyakarta were unified under one affiliation. After these refinements, 104 journal articles remained for analysis.

2.3. Data analysis and visualization

Several analytical techniques were employed to extract insights from a collection of publications. General information was summarized, and annual publication trends were analyzed to track the field's development. Country contributions were assessed based on article output and citation counts to identify the most active contributors. This study utilized VOSviewer software to collect, analyze, and visualize bibliographic data using CSV file formats. Additionally, bibliographic coupling of sources, authors, countries, institutions, and publications was examined, along with the co-occurrence of authors' keywords, to generate visual representations of the research landscape.

3. RESULTS AND DISCUSSION
3.1. General information and growth trends
Key details regarding the body of research on higher-order thinking in mathematics education are summarized in Table 2. Although the study considered publications from 2002 to 2022, the earliest research in this field was published in 2004. Over the period from 2004 to 2022, a total of 104 articles appeared across 77 Scopus-indexed journals.

Table 2. The collection's primary information

Description	Results	Description	Results
Primary data information		Authors	
Interval	2004:2022	Authors	271
Sources (Journals)	77	Authors of multi-authored documents	258
Documents (Articles)	104	Authors of single-authored documents	13
Distribution by Country	28	Colaboration between authors	
Contribution by Institutions	120	Single-authored documents	13
		Authors per document	2.60
		Documents per author	0.38

In the 104 publications, a total of 271 authors (an average of 2.60 per document) contributed. The majority of the documents, 258 (95.2%), were multi-author publications. Single-author documents were much fewer, representing only 4.8% (13 researchers). These researchers published 13 single-author documents, accounting for 12.5% of the total publications in the collection. Furthermore, a descriptive statistical analysis was conducted to determine trends in the number of publications and citations over the years. The changes in publication and citation numbers between 2002 and 2022 are shown in Figure 2.

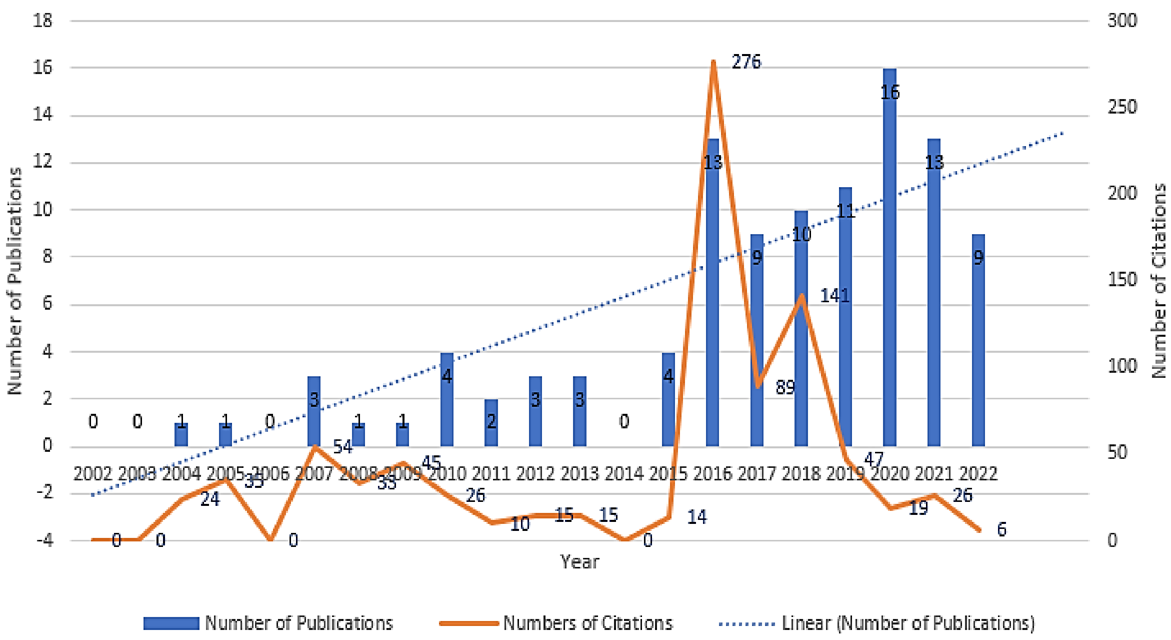

Figure 2. The total number of publications and citations by years

From Figure 2, it is understood that articles on higher-order thinking in mathematics education, as indexed in the Scopus database, started to be published in 2004. Between 2017 and 2021, more than half (approximately 56.7%) of all research articles were published. The largest increase in the number of articles compared to the previous year occurred in 2020, while the fastest decrease occurred in 2017 and 2022. Although the number of publications has fluctuated over the years, it has generally shown an upward trend. The trend of citations (excluding 2016) paralleled the trend of publications until 2018. The average number of citations in 2016 was higher than in the following years. Although the number of citations decreased annually from 2018 to 2022, it reached 141 in 2018, exceeding the average number of citations (41.7) over the years.

3.2. Citation analysis with countries

The Scopus database indicates that 28 countries contributed to the publications. However, only countries with at least three publications were analyzed. Among the 28 countries, 11 met the threshold. Table 3 presents the contributions and information of these 11 countries with the highest number of publications. Malaysian authors contributed the most publications, with 32 studies (30.8%). Following Malaysia, Indonesia had 20 papers (19.2%) and the United States had 19 papers (18.3%). Eight countries, with three to six articles each, are listed further down: Australia, Turkey, South Africa, China, Hong Kong, Nigeria, and Singapore. The United States also leads in citations, with 220 citations (approximately 26.9%), significantly more than the next countries: Malaysia with 191 citations (23.4%) and Indonesia with 149 citations (18.2%). The number of citations in other countries ranged from 6 to 69.

Table 3. The highest publications 11 countries

Country	Documents	Citations	Country	Documents	Citations
Malaysia	32	191	Israel	3	27
Indonesia	20	149	China	3	11
United States	19	220	Hong Kong	3	34
Australia	6	69	Nigeria	3	6
Turkey	6	38	Singapore	3	57
South Africa	4	15			

3.3. Citation analysis with institutions

An analysis of the Scopus database identified 104 published papers affiliated with 120 different institutions. However, only institutions with a minimum of two publications were considered for the study. Among these, 12 institutions met the inclusion criteria. As shown in Table 4, most of the affiliations listed are from Malaysia (50%). Four affiliations are from Indonesia, and one each from Taiwan and Brunei Darussalam. Universiti Teknologi Malaysia is the most productive institution with 9 papers (8.7%). Universiti Utara Malaysia (7 papers, 6.7%), Universiti Pendidikan Sultan Idris (5 papers, 4.8%), and Universiti Kebangsaan Malaysia (5 papers, 4.8%) are the other major contributors. Eight institutions are ranked lower with two to three articles each. Notably, Universitas Negeri Yogyakarta received a total of 102 citations (ranked 1st in citations) but published only three documents (ranked 4th in documents). This is due to its contribution to the two most-cited articles in the collection: Hadi *et al.* [36] with 66 citations and Falloon [37] with 34 citations.

Table 4. The most productive publishing 12 institutions

Institutions	Country	Documents	Citations
Universiti Teknologi Malaysia	Malaysia	9	87
Universiti Utara Malaysia	Malaysia	7	10
Universiti Pendidikan Sultan Idris	Malaysia	5	48
Universiti Kebangsaan Malaysia	Malaysia	5	15
Universitas Negeri Yogyakarta	Indonesia	3	102
Universitas Syah Kuala	Indonesia	3	3
Universitas Ahmad Dahlan	Indonesia	2	12
Universitas Negeri Malang	Indonesia	2	5
Universiti Putra Malaysia	Malaysia	2	15
National Taiwan University of Science and Technology	Taiwan	2	6
Universiti Brunei Darussalam	Brunei Darussalam	2	13
Universiti Sains Malaysia	Malaysia	2	1

Figure 3 illustrates the international collaboration network in higher-order thinking research in mathematics education, focusing on countries with at least five publications. The node size reflects the number of publications, while the line thickness between nodes represents the strength of cooperation. Based on the Scopus database, researchers from 28 countries contribute to this field. Notably, Malaysia, Indonesia, and the United States demonstrate strong international partnerships, with significant collaborations extending to Turkey, Israel, South Africa, China, and Australia.

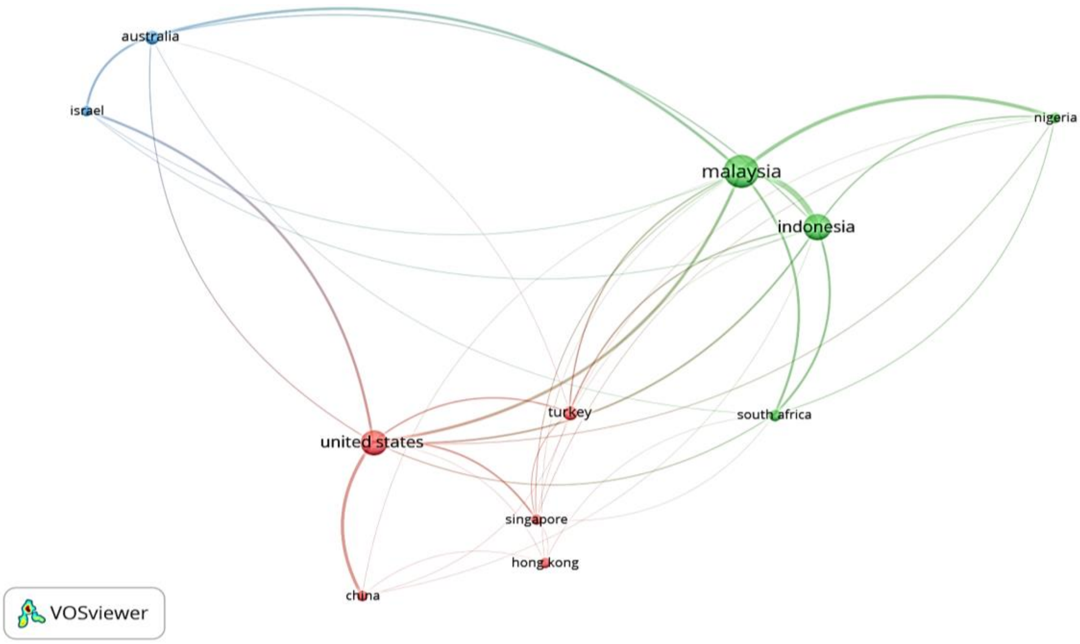

Figure 3. International cooperation network

3.4. Citation analysis with sources

As presented in Table 2, a total of 104 papers has been published across 77 different sources. However, for this study, only sources with a minimum of three publications were considered. Out of the 77 sources, six met this criterion. Table 5 highlights the top six journals that have contributed the most to research on higher-order thinking in mathematics education.

Table 5. The most published sources

Source	Documents	Citations
Eurasia Journal of Mathematics, Science and Technology Education	4	85
ZDM-International Journal on Mathematics Education	4	76
Journal on Mathematics Education	3	21
Educational Studies in Mathematics	3	59
International Journal of Mathematical Education in Science and Technology	3	22
Mathematics Education Research Journal	3	56

These six journals have collectively contributed 20 papers, representing 23.1% of the total publications and accumulating 337 citations, which account for 37.4% of all citations. Among them, the Eurasia Journal of Mathematics, Science and Technology Education and ZDM-International Journal on Mathematics Education have published the most papers on this topic, with four each. Meanwhile, the Journal on Mathematics Education, Educational Studies in Mathematics, International Journal of Mathematical Education in Science and Technology, and Mathematics Education Research Journal have each published three papers. Notably, the Eurasia Journal of Mathematics, Science and Technology Education has received the highest citation count (85 citations), largely due to a 2017 article that stands out as the most cited paper in the collection, with 45 citations [16].

3.5. Citation analysis with authors

Citation analysis was carried out to identify the most productive and effective authors in the field of higher-order thinking research in mathematics education. In VOSviewer, the minimum number of documents and citations by authors was chosen as at least two. Of the 271 authors, 18 met the thresholds. Table 6 shows the 18 most prominent authors sorted by total number of documents. The two most productive authors in this field are Abdullah, A. H., and Adnan, M. Four authors with three papers were third among the authors: Tajudin, N. M., Mokhtar, M., Puteh, M., and Zakaria, E. Authors from Malaysia seem to dominate the top three higher-order thinking authors in terms of documents. Only one author is from Indonesia, Australia, Taiwan, Nigeria, and Brunei Darussalam. Interestingly, there is a significant difference between the two ranks (in documents and in citations), i.e., the authors with the largest number of documents may not be the authors with the largest number of citations and vice versa. For instance, although there are 2 articles in the document, Retnawati, H. (100 citations) is the most cited. The second and third ranks are Abdullah, A. H. with 77 citations Tahir, L. M. with 53 citations.

Table 6. The most prominent 18 authors

Author	Country	Documents	Citations	Author	Country	Documents	Citations
Abdullah, A. H.	Malaysia	7	77	Chinnappan, M.	Australia	2	44
Adnan, M.	Malaysia	4	4	Ali, D. F.	Malaysia	2	47
Tajudin, N. M.	Malaysia	3	48	Ayub, A. F. M.	Malaysia	2	15
Mokhtar, M.	Malaysia	3	51	Ibrahim, N. N.	Malaysia	2	15
Puteh, M.	Malaysia	3	4	Tahir, L. M.	Malaysia	2	53
Zakaria, E.	Malaysia	3	15	Hwang, G. -J.	Taiwan	2	6
Retnawati, H.	Indonesia	2	100	Maat, S. M.	Malaysia	2	2
Abu, M. S.	Malaysia	2	16	Mun, S. H.	Nigeria	2	6
Alhassora, N. S. A.	Malaysia	2	16	Shahrill, M.	Brunei Darussalam	2	13

3.6. Citation analysis with articles

To identify the most influential articles on higher-order thinking in mathematics education, we set a minimum citation threshold of 25 in VOSviewer. Out of 104 documents, 10 met this criterion as shown in Table 7. The most cited article (73 citations) by Falloon analyzed data on 5- and 6-year-old students in a New Zealand primary school using Scratch Jnr to learn basic shapes, highlighting the benefits of integrating coding into early mathematics education [38]. The second most cited study (66 citations) by Hadi *et al.* [36] examined teachers' knowledge of HOTS and recommended socialization and training to enhance its implementation in mathematics education.

Three papers, each with 45 citations, rank third in influence. The first examines secondary school mathematics teachers' knowledge and practice of HOTS in Terengganu, highlighting differences based on demographic factors [16]. The second assesses the impact of game-based learning (GBL) on enjoyment, engagement, and deep learning in higher education, finding that games enhance higher-order thinking [39]. The third explores how pre-service primary teachers engage in meaningful mathematics teaching through online discussions, demonstrating a link between discussion conditions and synergistic interactions that foster HOTS [40]. Additional relevant studies include [37], [41]–[44].

Table 7. The most influential research

Authors	Title	Citations
Falloon [37]	An analysis of young students' thinking when completing basic coding tasks using Scratch Jnr. On the iPad	73
Retnawati *et al.* [35]	Teachers' knowledge about HOTS and its learning strategy	66
Abdullah *et al.* [16]	Mathematics teachers' level of knowledge and practice on the implementation of HOTS	45
Crocco *et al*. [38]	A proof-of-concept study of game-based learning in higher education	45
Llinares and Valls [39]	The building of pre-service primary teachers' knowledge of mathematics teaching: interaction and online video case studies	45
Bray and Tangney [40]	Enhancing student engagement through the affordances of mobile technology: a 21st century learning perspective on Realistic Mathematics Education	44
Tajudin and Chinnappan [41]	The link between HOTS, representation and concepts in enhancing TIMSS tasks	44
Martin *et al.* [42]	The interplay of teacher and student actions in the teaching and learning of geometric proof	35
Hadi *et al.* [36]	The difficulties of high school students in solving HOTS problems	34
Wong [43]	Confucian heritage culture learner's phenomenon: from "exploring the middle zone "to" constructing a bridge"	33

3.7. Keywords and terms analysis

Figure 4 presents the trends in keywords used in research on higher-order thinking in mathematics education. The analysis includes only keywords that appear at least three times. Out of 398 terms, 17 keywords met this criterion. Keywords that are closely related are categorized in similar colors, while the connections between them indicate their co-occurrence in publications. Additionally, the size of each keyword node reflects the frequency of its appearance in the analyzed publications.

Keyword analysis in higher-order thinking research in mathematics education highlight's key themes, including 'GeoGebra,' 'mathematics learning,' assessment, problem-solving, lesson study, and problem-based learning. The first study in this field, published in 2004 by researchers from Purdue University Indianapolis, initially received little attention (24 citations). Research activity remained low until 2015, with only 23 publications (22.1% of the total over two decades). However, interest surged between 2016 and 2022, accounting for 77.9% of publications (see Figure 2).

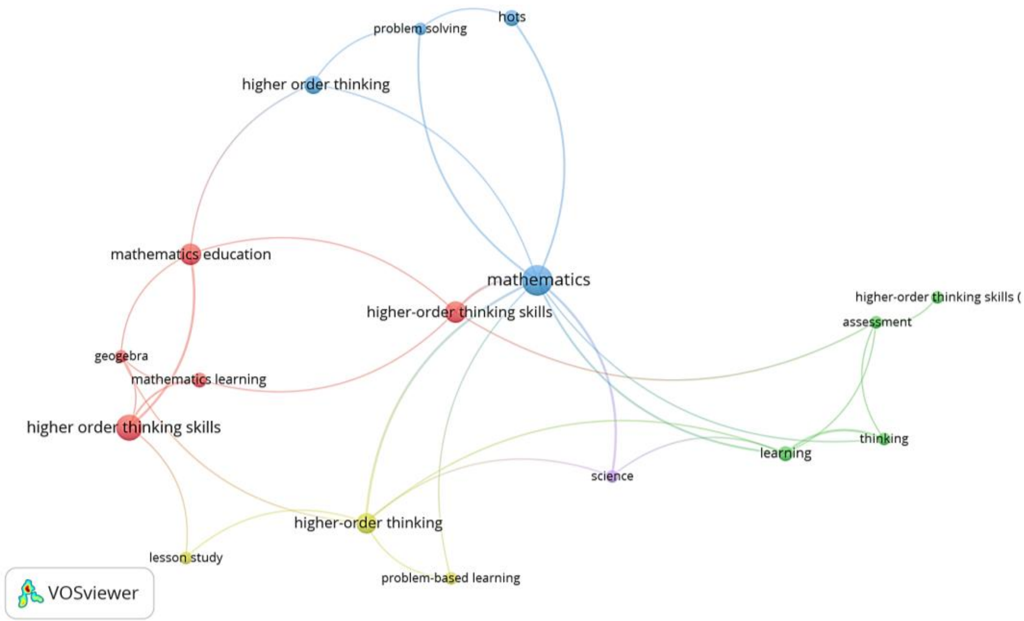

Figure 4. Keywords that appear most frequently in the keyword of publications

Malaysian researchers have played a major role, contributing 30.8% of all studies, while the United States leads in citations (24.4%) (see Table 3). Strong international collaborations exist, particularly among Malaysia, Indonesia, and the U.S. (see Figure 3). Malaysia's influence is further reflected in its leading institutions (see Table 4) and authors (see Table 6), underscoring its impact on higher-order thinking research in mathematics education.

Publications that have had significant influence in this field often associate HOTS with problem-solving. As noted in [45]–[50], HOTS are applicable across various aspects of learning, including knowledge construction, problem-solving [51], [52], self-direction, communication, and collaboration. This alignment is also reflected in the keyword analysis shown in Figure 4, which highlights the predominant research themes: problem solving, problem-based learning, mathematics learning, assessment, GeoGebra, and others. These themes can be categorized into three major groups, with some overlapping relationships.

4. CONCLUSION

This study examines the progression of research on higher-order thinking in mathematics education over the past two decades using bibliographic data from the Scopus database. The key findings are as follows: i) research in this field has been relatively limited, with only 104 studies published between 2004 and 2022, most of which emerged in recent years, particularly in 2016 and 2020; ii) although these studies have appeared in high-impact journals, they have received moderate attention, as indicated by an average citation count of 11.25; iii) Malaysia has played a leading role in this research area, contributing significantly through its institutions and authors; iv) strong research collaborations are evident among Malaysia, Indonesia, the United States, and other countries such as Australia, Turkey, South Africa, Israel, and Nigeria; v) the quality of publications in this domain is relatively high, as many are published in journals with strong citation records; and vi) key research themes include problem-solving, mathematics learning, and assessment.

This study provides a comprehensive bibliometric analysis based on the Scopus database. However, further in-depth investigations across other databases, such as WoS, ERIC, and Google Scholar, may be necessary to validate these findings, particularly in relation to higher-order thinking in mathematics education. Further studies on higher-order thinking in mathematics education may explore on sub-areas within mathematics learning and problem-solving, along with developing diverse assessment methods. Researchers interested in mathematics education should consider alternative avenues beyond the predominant research trends and influential articles mentioned earlier. Furthermore, scholars should prioritize strengthening international collaborations to enhance the quality and scope of future research endeavors.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT
Authors state no conflict of interest.

DATA AVAILABILITY
The data that support the findings of this study are available from the corresponding author, [HK], upon reasonable request.

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