Research trends in critical thinking skills in mathematics: a bibliometric study

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ABSTRACT

This study systematically reviews and analyzes previous studies' literature to identify the research gaps and the steps that must be taken for research on critical thinking in further mathematics education. Two methods, namely bibliometric analysis and descriptive content analysis, were used to achieve this goal. Data for the bibliometric analysis was obtained from the Scopus database, with the keywords "critical thinking" and "mathematics" Documents accessed are limited to the publication range of 2012-2022. The results show that the number of critical thinking research in mathematics has increased significantly, with a peak in 2021 of 65 articles; the United States has the most research and citations. The source that received the most citations was the journal Educational Studies in Mathematics. The evolution of the theme of critical thinking in mathematics began to link critical thinking with collaboration learning, mathematics education, teacher education, engineering, education, and collaborative learning. The quantitative approach with a student sample, tests as data collection instruments, and the analysis of variance (ANOVA) method is the methodology most often used by researchers. The results of this study are likely helpful for other researchers who will examine critical thinking skills in mathematics, namely as a research guide that they will develop. In addition, the existence of several research gaps can motivate other researchers to fill these gaps to contribute to improving the quality of critical thinking in mathematics.

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1. INTRODUCTION

Thinking is an individual's effort to understand something by processing information cognitively. The ability to think is a unique ability humans possess that distinguishes them from other creatures. Humans can develop their knowledge through thinking activities based on logical things. Critical thinking is one type of thinking that, for the last two decades, has become a keyword in both theory and pedagogical practice [1]. Dewey introduced the concept of critical thinking in 1933 with the term reflective thinking. Through reflective thinking, individuals indirectly learn to think critically by identifying and formulating problems, selecting relevant information, developing solution designs by combining experience and knowledge, and justifying the feasibility of solutions [2].

Several experts have defined critical thinking as the process of determining what to believe or do to determine the validity, reliability, and authenticity of the information or a particular claim [3]–[6]. According to Boran and Karakuş [7], critical thinking is a systematic mental process of solving problems, asking questions, and finding appropriate solutions through skills in evaluating available information. Someone who thinks critically will look at things from various perspectives, evaluate situations based on the reasons and scientific evidence found, and think actively by organizing his thoughts to explore and analyze logically through high-level reasoning activities [8]. Critical thinking is a cognitive skill that includes interpretation, analysis, evaluation, inference, explanation, and self-regulation as a basis for decision-making. Cortázar *et al*. [9] change into a broader explanation of argumentation and self-regulation into metacognition. Ennis, mentions that critical thinkers must have basic clarification skills, bases for decision, inference, and advanced clarification. Critical thinking is a cognitive process that actively and skillfully conceptualizes, analyzes, synthesizes, applies, and develops information obtained from reflection, observation, reasoning, experience, or communication as a guide in acting on these beliefs [10], [11].

In recent years, research on critical thinking and its application in mathematics has increased significantly [12], [13]. Critical thinking skills are needed in mathematical activities such as the problem-solving process. To begin solving individual problems simplifies complex settings by identifying the most relevant concepts and processes at the heart of the problem involving making decisions about what to pay attention to and what to ignore, developing an understanding of how essential concepts are connected, and generating representations realistic from the actual situation [14]–[16]. The literature study results show that no research collectively examines critical thinking in mathematics. Based on the results of this review, this study aimed to systematically review and analyze the existing research literature to obtain information related to research gaps. Furthermore, the results of this study are expected to contribute to further research on the steps that must be taken for further research related to critical thinking in mathematics.

2. RESEARCH METHOD

This study aimed to identify research gaps and steps to be taken for further research on critical thinking in mathematics. Two methods are used to achieve this goal: bibliometric analysis and descriptive content analysis. Bibliometric analysis was chosen because the bibliometric analysis can represent the state of all research from the past to the present based on several perspectives [17], [18]. Bibliometrics is a statistical check of information and quantitative analysis of bibliographic elements of scientific publications [19]. Based on that, researchers can use bibliometric analysis to examine the dynamics of all existing studies from a broader perspective [20]. Descriptive content analysis is used to look more profoundly and comprehensively at research trends in critical thinking in mathematics. According to Dinçer [21], descriptive content analysis methods aim to reveal patterns of themes in frequency or percentage to present the case as a whole and do not allow detailed inference.

In this method, quantitative and qualitative data can be used. Categorizing studies in a particular field carried out over a certain period is the most common study practice using descriptive content analysis. The descriptive content analysis method is used to descriptively identify research topics related to critical thinking in the existing field of mathematics. In addition, with this descriptive content analysis, the trend of critical thinking research in mathematics will be seen in terms of methodology. According to a study [22], researchers' general tendency to develop research related to critical thinking skills in mathematics can be known through checking quantitative and qualitative studies. In addition, to control study results, we used the selected reporting items for systematic review and meta-analysis protocol (PRISMA) technique. PRISMA's stages are clearly shown in Figure 1. Meanwhile, this study uses the Scopus database as data source.

2.1. Data collection

In collecting data for bibliometric analysis, "critical thinking" and "mathematics" are the keywords used to identify research related to critical thinking in mathematics education. Access to documents is done at Scopus on July 27th, 2022 with the field of social science research. Data collection for this bibliometric analysis collected 476 documents. The data collection for descriptive content analysis uses the PRISMA stage, which consists of four stages: identification, screening, eligibility, and inclusion. Identification in this data collection is based on the words "critical thinking" and "mathematics" in the article's title, abstract, and keyword. There is no filtering at this first stage. The strings used to search within=(article title, abstract, keywords), search documents=("critical thinking" and "mathematics"), published from=(all years) to=(present), added to Scopus=(anytime). At this stage, 927 documents were produced.

Furthermore, screening is carried out, namely document screening based on inclusion/exclusion criteria. The inclusion criteria are open access, the year of publication is in the 2012-2022 range, the research area is a social science, the type of document is articles and conference papers, the source type is journals and proceedings, and the language used is English. This was done to ensure the novelty of the research and a reasonable amount of research so that it could be examined comprehensively. This stage resulted in 133 articles. In the eligibility stage of the 133 articles, a review was carried out on the title and abstract sections. The eligibility stage resulted in 54 articles by the research objectives based on the title and abstract. The last stage is included, where filtering is based on reading the text as a whole. The steps included producing 49 documents.

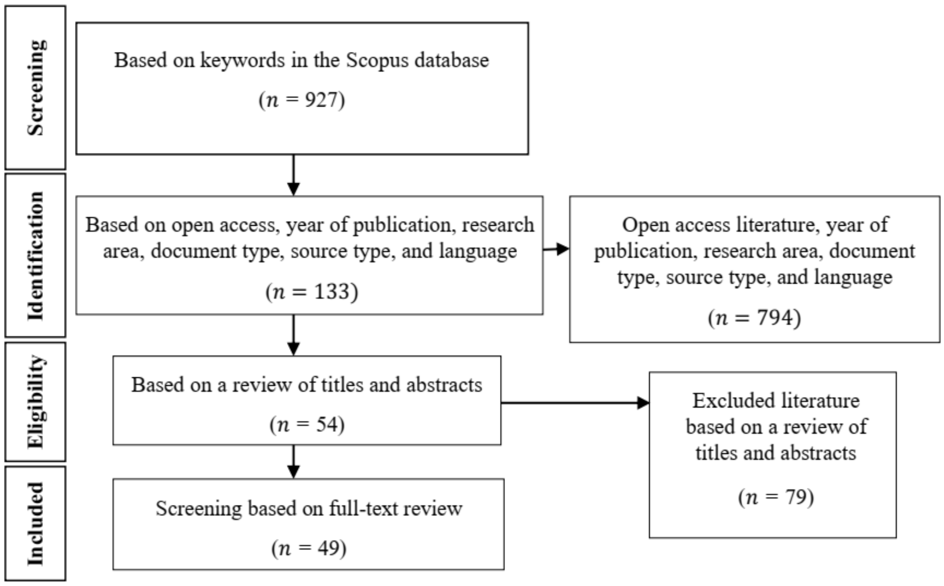

Figure 1. Flowchart of PRISMA stages

2.2. Data analysis

Bibliometric analysis was performed using the Bibliometrix software package in the RStudio program. To simplify the analysis, the bibliometric version of the software ready to be used without coding is used, namely Biblioshiny. Bibliometrix was formerly a quantitative evaluation tool for publication and citation data. Today, bibliometrics is used in almost all scientific fields to evaluate the growth, maturity, leading authors, conceptual and intellectual maps, and trends of the scientific community [23]. Furthermore, the data analysis method for descriptive content analysis is carried out by collecting similar data within the framework of specific concepts and themes for further interpretation. The selected articles were grouped as a publication classification developed by [24] in the data analysis process. The grouping of articles is based on the information in the articles, such as the author's name, year of publication, research methods used, subject, number of samples taken, research instruments, and data analysis techniques. Data related to the content of the article was recapitulated using Microsoft Excel. Furthermore, after the data has been recorded based on content, the data are grouped according to the criteria that have been set. Finally, before interpreting the data, a percentage calculation is carried out related to the frequency of the data obtained.

3. RESULTS AND DISCUSSION

3.1. Bibliometric analysis

A total of 476 articles were generated in a search on the Scopus database with the keywords “critical thinking” and “mathematics” in the field of social science. Then, an analysis was carried out on the 476 articles that had been found. Following are the results of bibliometric analysis using Biblioshiny software.

3.1.1. Annual scientific production distribution

The analysis using Biblioshiny shows that the number of research on critical thinking in mathematics has increased significantly since 2016. Although in 2017 there was a downward trend, the following year experienced a rapid increase. As presented in Figure 2, the number of publications on critical thinking in mathematics is the most in 2021, which is 65 documents.

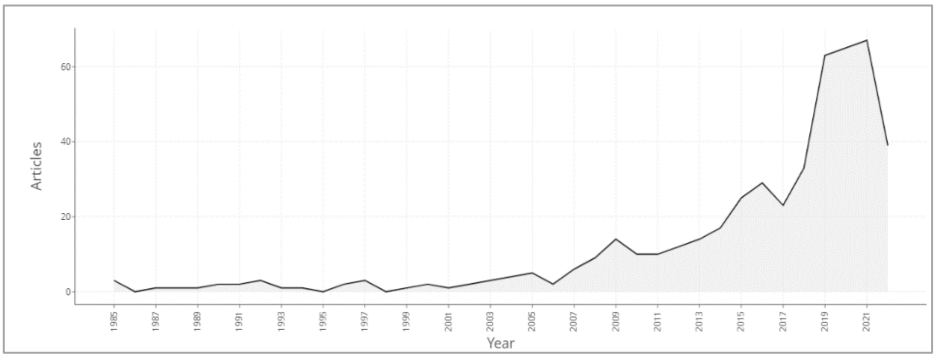

Figure 2. Annual scientific production distribution

3.1.2. Country scientific production distribution

The distribution of country scientific production is shown in Figure 3, where the area in blue shows the countries that produce critical thinking research in mathematics. The darker the blue, the more critical thinking articles in mathematics produced by that country. The country scientific production data in more detail is shown in Table 1. In Table 1, the country that published the most research related to critical thinking in mathematics from 1985 to 2022 is the United States (US), with 273 publications. Indonesia occupies the second rank of as many as 120 publications.

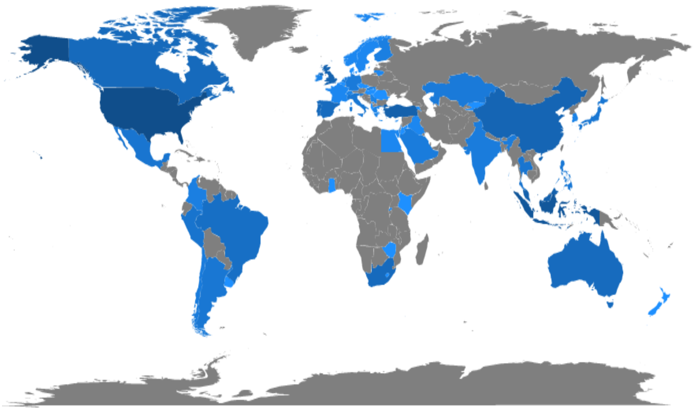

Figure 3. Country scientific production distribution

Table 1. Country scientific production distribution

Country	*f*	%	Country	*f*	%	Country	*f*	%
US	273	31.45	Germany	6	0.69	Iraq	2	0.23
Indonesia	120	13.82	Kazakhstan	6	0.69	Lithuania	2	0.23
Turkey	53	6.11	Chile	5	0.58	Norway	2	0.23
Malaysia	50	5.76	India	5	0.58	Sweden	2	0.23
UK	43	4.95	Netherlands	5	0.58	Albania	1	0.12
China	35	4.03	Saudi Arabia	5	0.58	Armenia	1	0.12
Portugal	25	2.88	Slovenia	5	0.58	Belgium	1	0.12
Canada	24	2.76	Colombia	4	0.46	Czech Republic	1	0.12
South Africa	23	2.65	Finland	4	0.46	Denmark	1	0.12
Australia	21	2.42	Greece	3	0.35	Ghana	1	0.12
Spain	21	2.42	Ireland	3	0.35	Hungary	1	0.12
Brazil	15	1.73	Rwanda	3	0.35	Jordan	1	0.12
Peru	10	1.15	Serbia	3	0.35	Kenya	1	0.12
Mexico	9	1.04	Singapore	3	0.35	Kyrgyzstan	1	0.12
Thailand	9	1.04	Slovakia	3	0.35	Lesotho	1	0.12
Argentina	8	0.92	South Korea	3	0.35	New Zealand	1	0.12
Israel	8	0.92	Switzerland	3	0.35	Romania	1	0.12
Italy	8	0.92	Cyprus	2	0.23	Uruguay	1	0.12
Japan	8	0.92	Egypt	2	0.23	Zimbabwe	1	012
Philippines	7	0.81	France	2	0.23			

3.1.3. Most cited countries

Analysis using Biblioshiny shows that the US is the country that receives the most citations for critical thinking research in mathematics. Figure 4 shows as many as 1671 citations for critical thinking research in mathematics obtained from 1985-2022. This number is very significant compared to the number of citations obtained by Turkey, which is 320.

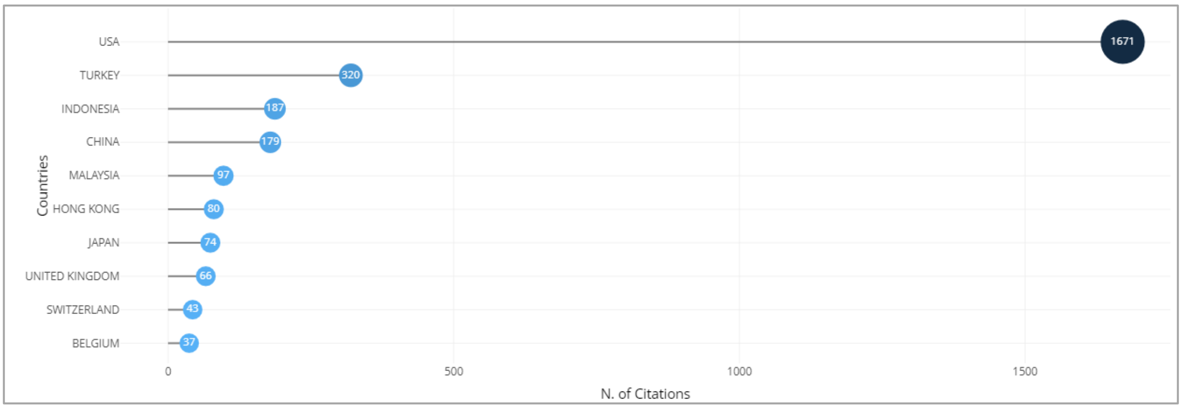

Figure 4. Most cited countries distribution

3.1.4. Most cited sources

Based on Figure 5, the most cited source for research related to critical thinking in mathematics is the international journal Educational Studies in Mathematics. This journal is a journal that presents new ideas and research developments in the field of mathematics education. There were 104 citations have been obtained in this journal related to critical thinking research in mathematics.

Figure 5. Most cited sources distribution

3.1.5. Most global cited documents

The results of the bibliometric analysis show that the document entitled "Education for life and work: Developing transferable knowledge and skills in the 21st century" is the document that receives the most citations from research related to critical thinking in mathematics. The article written by Pellegrino and Hilton [25] obtained citations 421. This article contains 21st-century skills, one of which is the ability to think critically, where efforts to improve these skills must synergize with learning. Figure 6 shows most global cited documents distribution.

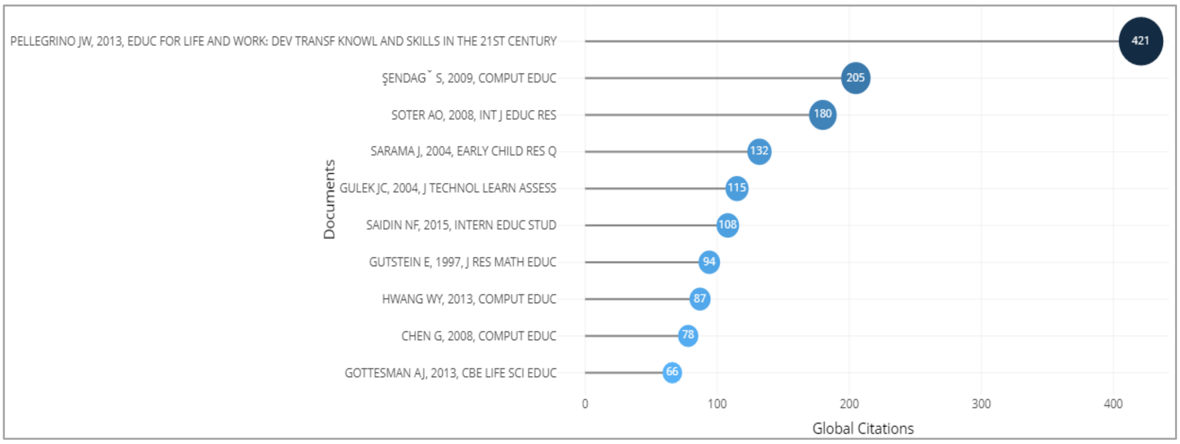

Figure 6. Most global cited documents distribution

3.1.6. Co-occurrence network

The co-occurrence network of critical thinking research in mathematics is shown in Figure 7. This data is obtained from the keywords used by the author. Figure 7 shows the relationship between the keywords used by the author. Co-occurrence results show that there are two main clusters, namely critical thinking and mathematics.

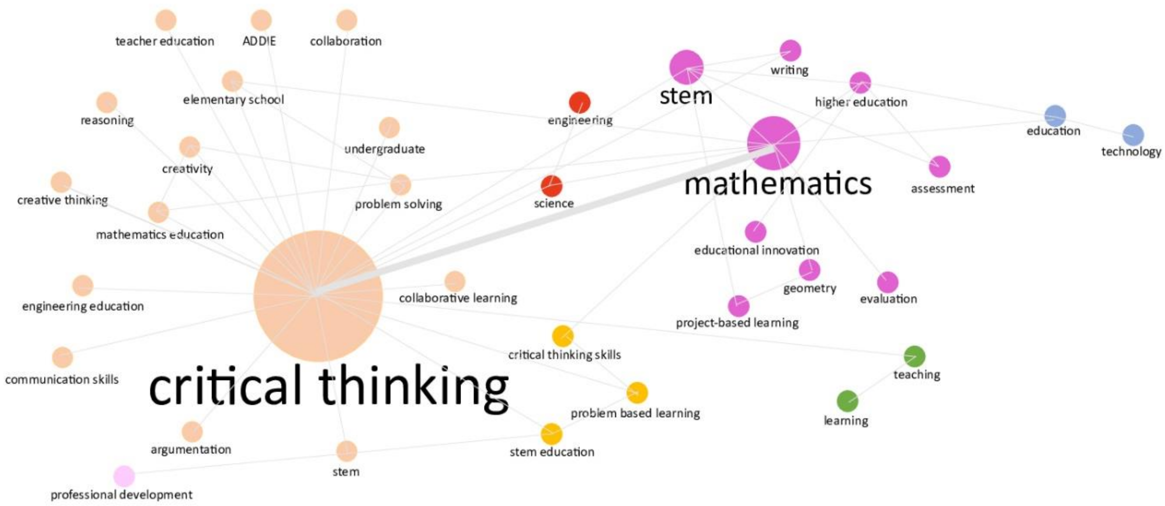

Figure 7. Co-occurrence network

3.1.7. Thematic evolution

Furthermore, Figure 8 shows a thematic evolution map obtained through bibliometrics that describes the development of keywords over time in critical thinking research in mathematics. The map was created by considering two stages, namely 1985-2018 and 2019-2022. For example, from 1985-2018, collaboration learning, mathematics education, teacher education, engineering education, collaborative learning, and creativity were separated from the critical thinking theme. However, in 2019-2022, there is a link between critical thinking and collaborative learning, mathematics education, teacher education, engineering education, and collaborative learning.

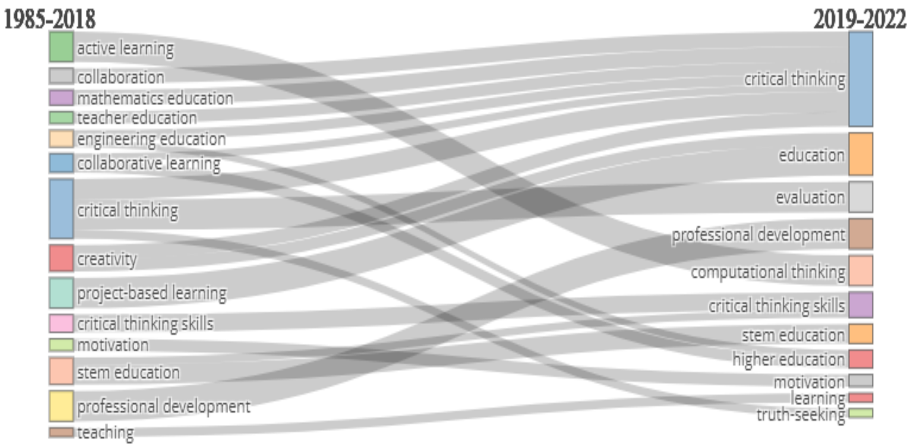

Figure 8. Thematic evolution

3.2. Descriptive content analysis

The following presents a descriptive analysis of 49 selected documents based on the PRISMA stages related to the theme of critical thinking in mathematics. These documents are documents that have been published in the 2012-2022 period. The descriptive analysis includes subject area; research approach and design; sampling methods, sample population, sample sizes; research instruments; and data analysis method.

3.2.1. Subject area

The identification results show that 28 areas are the focus of critical thinking research in mathematics. These areas include problem-based learning; mathematical teachers; online learning; questioning; science, technology, engineering and math (STEM); reflective thinking; contextual learning; learning models; learning media; problem solving; subjects; mathematics problems; action, process, object, and schema (APOS) theory; justification; creative thinking; mathematics competition; realistic mathematics education (RME); algebra; pedagogy belief; argumentation; concept attainment model; academic performance; adventure learning, 21 century; professional life; flipped classroom; and guided inquiry. The spread of the research focus is more clearly seen in Figure 9.

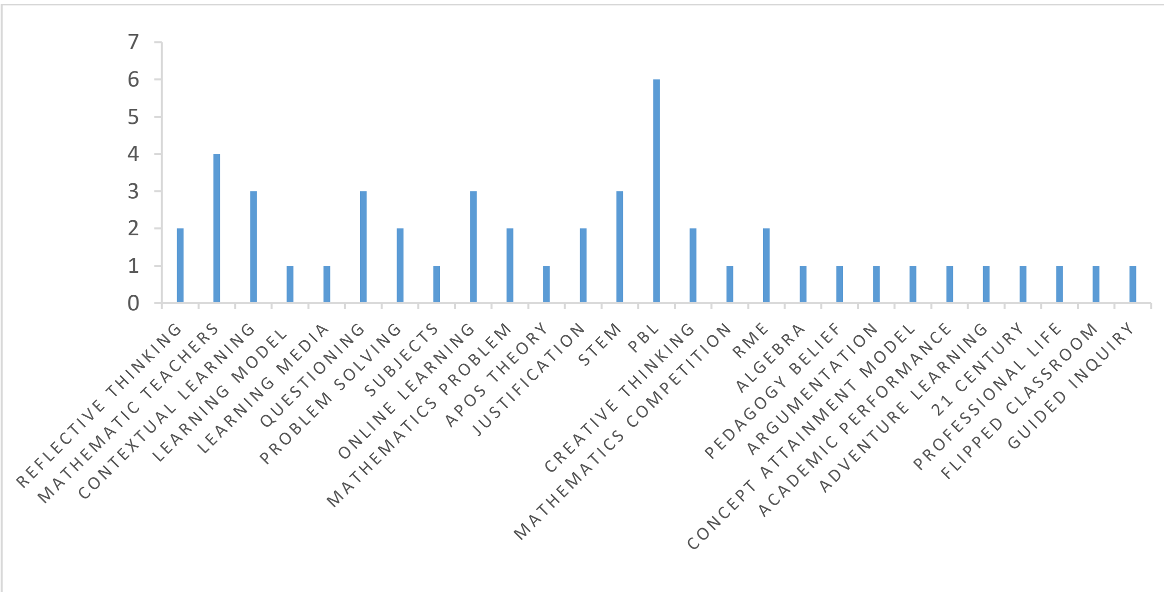

Figure 9. Distribution of themes/focus of research

3.2.2. Research approach and design

Researchers use various approaches and research designs in critical thinking research in mathematics. There are three main approaches used by researchers, namely qualitative, quantitative, and mixed methods approach. Of the three approaches, the quantitative approach is the most frequently used. Of the 49 documents analyzed, 27 documents used a quantitative approach, 18 used a qualitative approach, and the rest used a mixed method. Figure 10 shows a Tree Map of the approach and design of mathematical thinking research carried out by researchers from 2012 to 2022.

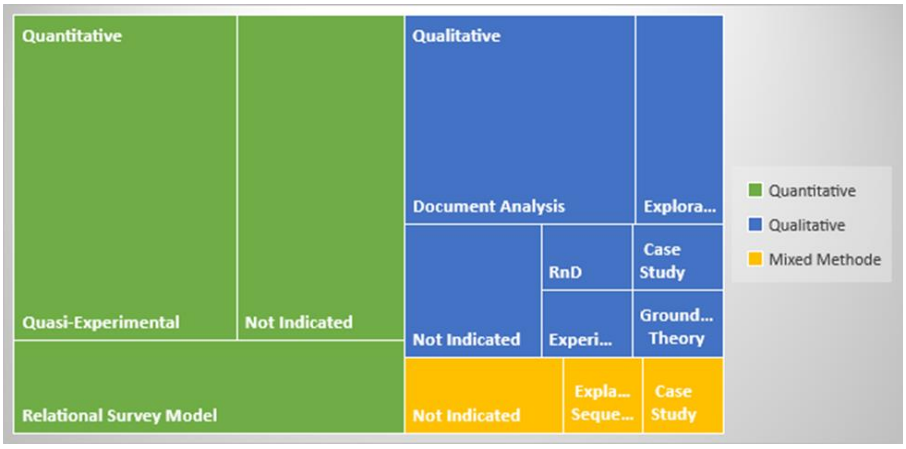

Figure 10. Tree map research approach and design

The design of critical thinking research in mathematics is also diverse. Among them, the quantitative approach and several research designs used are the relational survey model and quasi-experimental. For the qualitative approach, the design used is document analysis, exploration, research and development, experimental, case studies, and grounded theory. Meanwhile, the mixed methods design approach is explanatory sequential and case studies. The distribution of research designs used by research that has been fully published is shown in Table 2.

Table 2. Data research approach and design

Research approach	Design	Frequency	%
Quantitative	Relational Survey Model	6	22.22
	Quasi-experimental	12	44.44
	Not indicated	9	33.33
	Total	27	100.00
Qualitative	Document analysis	8	44.44
	Exploratory	3	16.67
	RnD	1	5.56
	Experimental	1	5.56
	Case study	1	5.56
	Grounded theory	1	5.56
	Not indicated	3	16.67
	Total	18	100.00
Mixed Method	Explanatory sequential	1	25.00
	Case study	1	25.00
	Not indicated	2	50.00
	Total	4	100.00

3.2.3. Sampling methods, sample population, and sample sizes

The following identification is on the part of the participants or research subjects. This section observes three things: the sampling methods, sample population, and sample sizes. From the results of the analysis, students became the most researched population. The sampling method used was 38.78% random sampling, 44.9% purposive sampling, and 2.04%, respectively, for snowball sampling, disproportionate stratified sampling, and cluster sampling. In comparison, the sample size that researchers most often use is in the range of 11 to 100 samples. Table 3 shows the results of the participant analysis.

Table 3. Data, sampling methods, sample population, and sample sizes

Research subject		Fr	%
Sample population	Mathematics teachers	4	8.16
	Preservice teacher	8	16.33
	Higher education	12	24.49
	ONMIPA student	1	2.04
	Upper secondary student	6	12.24
	Vocational student	1	2.04
	Lower secondary student	11	22.45
	Primary student	5	10.20
	Student (Not indicated)	1	2.04
Sampling methods	Random sampling	19	38.77
	Purposive sampling	22	44.89
	Snowball	1	2.04
	Disproportionate stratified sampling	1	2.04
	Cluster sampling	1	2.04
	Not indicated	5	10.20
Sample size	10 and below	5	10.20
	Between 11-100	18	36.73
	Between 101-300	11	22.44
	301 and above	3	6.12
	Not indicated	12	24.49

3.2.4. Research instruments

What needs to be identified in terms of methodology is a research instrument, namely a tool to collect data. From the analysis results, eight types of research instruments are used to collect critical thinking data in mathematics: tests, questionnaires, interviews, observations, documentation, scales, surveys, and validation sheets. Among the eight instruments, the test is the most often used by researchers. 79.59% of researchers used test instruments to collect research data. Table 4 shows the distribution of the number of instruments used.

Table 4. Research instruments

Research instruments	Frequency	%
Test	39	79.59
Questionnaire	6	12.24
Interviews	13	26.53
Observation	7	14.29
Documentation	2	4.08
Scale	3	6.12
Survey	2	4.08
Validation Sheets	1	2.04

3.2.5. Data analysis method

Data analysis methods were also analyzed in this descriptive content analysis research. Table 5 shows that for quantitative research, data were analyzed using descriptive statistics, t-test, ANOVA, multivariate analysis of variance (MANOVA), analysis of covariance (ANCOVA), correlation analysis, and analysis regression. In qualitative research, the analytical methods used are descriptive, Q-Cohran, and the NVivo application. Some use five systematic stages: data preparation, data collection, data reduction & categorization (coding), displaying, and concluding. For the mixed method approach, ANOVA and MANOVA were used for quantitative data, and factor maximum likelihood (FML)-principal factor analysis (PFA) for qualitative data.

This study aims to review and analyze the literature of previous studies systematically to identify the research gaps and the steps that must be taken for research on critical thinking in mathematics education in the future. To achieve this goal, the researcher uses bibliometric analysis to reveal the year of publication, country, and citations by source and country, as well as keywords often used in research on critical thinking in mathematics. In addition, descriptive analysis using a credible database, namely Scopus, is used to identify subjects, methodology, research design, sample groups, research instruments, and data analysis techniques in studying critical thinking in mathematics.

Table 5 Data analysis method

Data analysis method		Fr
Quantitative	Descriptive statistics	5
	T-test	5
	ANOVA	9
	MANOVA	3
	ANCOVA	2
	Analysis correlation	4
	Validity, reliability	2
	Analysis Regression	2
	Not Indicated	2
Qualitative	Descriptive	6
	Data preparation, collection, reduction & categorization (coding), displaying and concluding	3
	Vivo	1
	Interpretative	1
	Q-Cohran	1
	Not Indicated	4
Mixed methods	Quantitative	
	ANOVA	1
	MANOVA	1
	Qualitative	
	Factor maximum likelihood	1
	Principal factor analysis	1
	Not Indicated	2

Based on the bibliometric results in Figure 2, the first research that met the search category for the theme of critical thinking in mathematics was published in 1985. After that, research on critical thinking in mathematics experienced an increasing trend from year to year based on the number of publications observed after 2006. In recent years the number of publications reached 70 documents. This shows that the interest in critical thinking in mathematics is increasing and growing. Critical thinking skills are high-level cognitive skills needed in every developing field [25]–[27]. On the other hand, mathematics is one of the fields that supports the development of critical thinking skills [28]–[30]. The bibliometric results also show that 59 countries produce research on critical thinking in mathematics. In terms of the number of publications, the US is the country with the highest number of publications from 1985 to 2022. Likewise, regarding the number of citations, the US ranks the highest, 1671. This is to the research results of [31], [32], which state that most critical thinking research is conducted in the US. Since the 1940s, essential steps towards the practice of critical thinking have been taken in the US, such as the Delphi panel. In addition to being reviewed from the US progress in developing critical thinking skills, researchers found indications that there is a dearth of studies in the field for countries other than the US, even though critical thinking skills are an ability that is demanded in national policy documents in many countries [33].

Furthermore, about the cited documents, documents written by Pellegrino and Hilton obtained citations 421. This article contains 21st-century skills, one of which is the ability to think critically, where efforts to improve these skills must synergize with learning. According to bibliometrics, the most widely used reference sources for critical thinking research in mathematics are the journal Education Studies in Mathematics and Computer & Education. These results provide information to researchers who will find references to support theoretical studies of critical thinking research in mathematics. Regarding the frequency of the most frequently used keywords, it can be seen in Figure 7 that the most used keywords are critical thinking and mathematics. In comparison, the keywords that are rarely used are collaboration; Analysis, Design, Development, Implementation, and Evaluation (ADDIE); argumentation; technology; reasoning; and collaborative learning. Based on the link analysis of these general keywords, the main research areas in critical thinking in mathematics can be identified. In addition, keywords can be used to identify evolutionary themes. Through analyzing this evolutionary theme, information about the development of keywords can be obtained from time to time in critical thinking research in mathematics. Therefore, keywords are essential in determining research trends because they are informative for researchers [34], [35].

A systematic literature review is helpful for clearly identifying gaps in critical thinking research in mathematics so that future researchers can determine the proper steps. One of them is to explore the focus areas of critical thinking themes in mathematics. Through analysis of descriptive content limited to articles published in 2012-2022, various themes in the research of critical thinking in mathematics are divided into 28 themes. Most critical thinking research in mathematics focuses on efforts to improve critical thinking skills through specific methods or strategies. According to a studies [36], [37], the current focus of mathematics learning is more demanding on conceptual understanding and the ability to justify rather than just applying mathematical rules, so mathematics has a potential role in developing critical thinking skills [38].

Given the demands of competence in the 21st century, future mathematics research must focus on studies that integrate critical thinking skills with other competencies such as creative thinking, communication, and collaboration. The research method is part of the research framework [39]. The data presented in Table 2 on critical thinking research methodology in mathematics illustrates the structural basis of the research. This will be a guide for researchers before conducting scientific studies. The results of the descriptive content analysis revealed that almost 50% of the research was designed using a quantitative approach. The basic principle of quantitative research is to present and evaluate the data collected by descriptive and statistical means. In comparison, qualitative research occurs naturally and is interpreted holistically so that research results are discussed more fully and in various ways [40]. So, it is recommended for future research on critical thinking in mathematics to conduct further qualitative research that examines concepts and research areas more deeply. In addition, mixed methods are also needed to handle qualitative and quantitative data by changing different data sources from one to another to verify each other.

Descriptive content analysis on critical thinking in mathematics between 2012 and 2022 revealed that most research was conducted with university students. Higher education is responsible for developing critical thinking skills, which ultimately leads to higher-order thinking [41]–[43]. Table 3 shows the subjects other than students are mathematics teachers, prospective mathematics teachers, elementary, junior high, high school, and vocational students. Critical thinking skills are important for students attending any educational program [44], [45]. In addition, the teacher is an important factor in teaching critical thinking skills [46]–[49]. So that research on critical thinking in mathematics can be carried out on teachers, prospective teachers, and students at every level.

The results of the descriptive content analysis on the sampling method show that the methods often used are random and purposive. Regarding sample size, most researchers work with small sample sizes. In the articles analyzed, a sample size of 11–100 participants were the most frequently used measure. For future research on critical thinking in mathematics, it is suggested that researchers conduct research with a larger sample to obtain more generalizable results. In terms of research instruments, the results of descriptive content analysis show that the test is the most frequently used data collection tool in critical thinking research in mathematics. This is a consequence of developing critical thinking skills evaluation tools as test instruments in essays and rubrics [50]. So, it should be noted by researchers that the test is a reliable tool to obtain research data about critical thinking skills in mathematics.

4. CONCLUSION

The bibliometric analysis and descriptive content analysis results present the existing literature's overall systematics and contribute to identifying potential gaps in critical thinking research in mathematics. In addition, this research provides information to readers about sources and documents that need to be studied as the basis for critical thinking research in mathematics. The results also reveal a need for critical thinking research in mathematics in many other countries. The USA can be used as a reference in this study. Research trends can also be used to determine the theme of critical thinking research in mathematics. Critical thinking research frameworks in mathematics, such as focus areas of study and methodologies in research, have been generated in this study. The database used in this study is limited to the Scopus database, so the resulting critical thinking research framework in mathematics is also limited. For further research, the development of the findings of this research can be done using keyword string searches and different alternative databases. The results of this study are likely helpful for other researchers who will examine critical thinking skills in mathematics, namely as a research guide that they will develop. In addition, the existence of several research gaps can motivate other researchers to fill these gaps to contribute to improving the quality of critical thinking in mathematics.

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