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A bibliometric exploration of research in mathematics education (2020–2024)

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Abstract
The rapid development of technology in society makes research in mathematics education relevant. However, their comprehensive analysis is complicated due to some factors (different scientific journals and publishers, many documents, etc.) The article aims to analyze the publication landscape to understand the current state of mathematics education, identify key trends, and formulate strategies for further development of this field. The research method was bibliometric analysis. The data for this study were obtained from the Web of Science core collection on December 3, 2024. The objects of analysis were the number of publications, authors, geographical and institutional distribution of publications, citation of publications, and keywords. We analyzed publications from 2020 to 2024 and used the VOS (visualization of similarities) methodology in the VOSviewer computer program. We obtained the following characteristics of the publication landscape: quantitative trends for articles, reviews, conference materials, the most active authors, the most cited publications, and the top 5 countries with the most significant number of such publications. We identified key areas of research in mathematics education based on keyword networks and predicted vectors for further development of mathematics education.

Keywords: bibliometric analyses, math education, math learning, math teaching, review, research

INTRODUCTION

The current stage of development of society is characterized by the ultra-rapid development of information technologies (IT), which significantly affects all spheres of life, including education (Yurchenko et al., 2023). These changes require a rethinking of traditional approaches to learning since integrating IT into schooling leads to the transformation of forms, methods, and means of learning (Mufron et al., 2024). Teaching mathematics in any country has always been difficult for teachers (Karalı, 2022). This is due to the abstraction of mathematical concepts and individual characteristics of the perception of educational material (especially critical thinking, which includes skills of analysis, synthesis, evaluation, comparison, etc.) (Yumiati & Kusumah, 2019). Therefore, obtaining high-quality mathematical education is becoming more and more relevant due to the global digitalization of various processes, the growing role of automated systems and artificial intelligence (AI) (Drushlyak et al., 2025), and the in-demand skills of the 21st century (Gravemeijer et al., 2017).

Teachers' professional activities, as a rule, are based on generalizations of local experience (own, regional, or national). The selected teaching strategies, which are locally effective, are subsequently described in scientific publications. However, such publications are scattered among different sources, complicating their systematization and analysis. The number of scientific papers in mathematical education is extremely large. various scientific documents related to mathematical education. This creates significant difficulties for researchers (Rodrigues et al., 2014; Zhou et al., 2015) who want to get acquainted with current achievements in this field. Limited access to some sources, a variety of publication languages, and different types of scientific papers (articles, monographs, conference abstracts, etc.)

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Contribution to the literature

- This paper provides an up-to-date bibliometric overview of global research in mathematics education for the period 2020–2024.
- It identifies major publication trends, influential authors and countries, and emerging thematic clusters using VOSviewer-based visualization.
- The findings offer valuable insights into the current state and future directions of mathematics education research, supporting evidence-based decision-making in scholarly and educational policy contexts.

make it impossible for one person to familiarize himself with all available materials fully. In such conditions, there is a need to get a general picture of the publication landscape to identify key trends, problems, and research areas in mathematical education.

Therefore, **the article** aims to analyze the publication landscape to understand the current state of mathematical education, identify key trends, and form strategies for further development of this field.

RESEARCH DESIGN

Research Method

The research method was bibliometric analysis, which allows you to systematize large amounts of scientific data and identify the leading research centers, the most cited works, key topics, etc. (Jia et al., 2014). Bibliometric analysis as a research method makes it possible to describe the publication landscape and identify gaps in existing research, which can become the basis for further scientific research (Chigbu et al., 2023; Li & Hale, 2016). It allows us to generalize the experience of different countries and regions, which is especially important in the globalization of education and the search for universal approaches to teaching mathematics in the context of rapid technological development. Thanks to bibliometric analysis, we can investigate trends in the development of mathematical education through the quantitative study of the history of publications and identify the main features and prospects for further progress in this area (Geng et al., 2017). Such an analysis provides an opportunity to study scientists' publication activity, assess the level of cooperation between authors, institutions, or countries, and highlight the most influential works and trends (Song et al., 2019). It also makes it possible to avoid the repetition of already performed research and the use of outdated information or incorrect theories, which significantly increases the accuracy and relevance of scientific papers (Jia et al., 2014; Li & Hale, 2016).

Data

We obtained the data for this study from the Web of Science (WoS) core collection scient metric database on December 3, 2024. We chose the WoS database for several reasons: WoS is a universally recognized scient metric database for the international scientific community (Yang et al., 2013); the database provides a wide coverage of various scientific areas to identify interdisciplinary relationships; the database indexes high-quality publications, which ensures the reliability and authority of the analysis results (Korom, 2019); the database has digital tools that allow you to filter/research publications by year, scientific direction (field of knowledge), type of publication, as well as citation of publications, activity of each author, affiliation of authors, institutions, countries, etc. (Birkle et al., 2020); the database accumulates publications of various types over a significant period of time, which allows you to assess the overall publication activity of scientists in the context of the problem research; The database makes it possible to search for documents by various metadata, including keywords, which allows you to identify research objects and predict trends in the development of problems of mathematical education; the database allows exporting data in various formats for further analysis using specialized software (for example, VOSviewer, or SPSS) (van Eck & Waltman, 2010).

A comprehensive bibliometric study of publications on mathematics education should cover its various aspects: general systems and principles (education), teaching methods and strategies (teaching), and individual assimilation of knowledge and skills (learning). Therefore, to identify the necessary publications, we used the "TOPIC" parameter in the search field and formed queries by words that were applied to the search (title, abstract, keyword plus, and author keywords):

Query A–words (math AND education) OR (mathematics AND education);

Query B–words (teaching AND math) OR (teaching AND mathematics);

Query B–words (learning AND math) OR (learning AND mathematics).

We did not use the "all fields" search box because this field searched for other parameters, such as the names of journals or conferences that might have published a paper unrelated to the research problem.

Each publication in WoS has metadata: year of publication, authors, addresses, title, abstract, journal source, thematic categories, and list of sources used. We exported the metadata of the publications for further

Table 1. Search results in the topic field for "education/teaching/learning"

Words to search for	Number of scientific publications			
	Overall	Article	Proceeding paper	Review article
Education	1,634,718	1,217,774	202,242	67,022
Teaching	669,255	461,833	130,088	17,460
Learning	2,413,780	1,580,278	641,632	93,052

analysis in MS Excel and VOSviewer. The objects for analysis were:

(1) the number of publications,

(2) authors,

(3) geographical and institutional distribution of publications and cooperation,

(4) citation of publications,and

(5) keywords.

We analyzed publications for the last 5 years (the period from 2020 to 2024). Still, to understand the dynamics of changes, we sometimes tracked the data in general (from 1970 to 2024), which we noted separately when presenting the results. We considered only scientific publications of the "article," "proceeding paper," and "review article" types since they

(1) provide up-to-date information on research in the field of mathematics education,

(2) have a complete set of metadata,

(3) collectively make up the vast majority of scientific publications,

(4) undergo a thorough expert assessment, and

(5) ensure the representativeness of research.

We did not consider other types of documents indexed by the WoS (retracted publication, editorial material, book chapter, letter, data paper, book review, and publication with expression of concern) due to their debatable involvement in the landscape of publications on the problems of mathematics education or incomplete metadata.

To determine the most productive authors, we generated a generalized query "(math or mathematics) and (education or teaching or learning)" in the "TOPIC" field.

VOS (visualization of similarities) methodology in computer program VOSviewer (www.vosviewer.com) provides visualization of relationships through two-dimensional maps with clusters. The distance between elements on the map reflected the degree of affinity (van Eck & Waltman, 2010). Each cluster was marked with a separate color (van Eck et al., 2010; Waltman et al., 2010). The size of objects on maps is characterized by the number of occurrences (the more occurrences, the larger the circle for denoting the object) (Rizzi et al., 2014). At the same time, the X and Y axes did not have a specific value (Khalil & Crawford, 2015).

RESULTS

Number of Publications and Growth Trends

The number of publications is an important indicator for understanding the dynamics of the development of the scientific field. To have a general idea of the number of scientific publications related to education, we first searched for the words "education," "teaching," and "learning." We did not limit the year of publication. We presented the results on the number of documents in **Table 1**.

We recorded a total of about 4 million publications (3,998,027), the metadata of which contains at least one of the words "education," "teaching," and "learning." Among these publications, at least 1.6 million publications (1,627,886) contain at least one of the words "education," "teaching," or "learning" in their title (title field).

A much larger number of publications than others are related to "learning"–the total number is 2,413,780 documents, among which are 1,580,278 articles, 641,632 proceedings papers, and 93,052 review articles. From this, we conclude that scientists do not always use words in the title of the publication that directly identify education/training/teaching as a research problem. The results of the query "learning" show the highest number of publications, which underlines the significant interest of scholars in the cognitive aspects of learning.

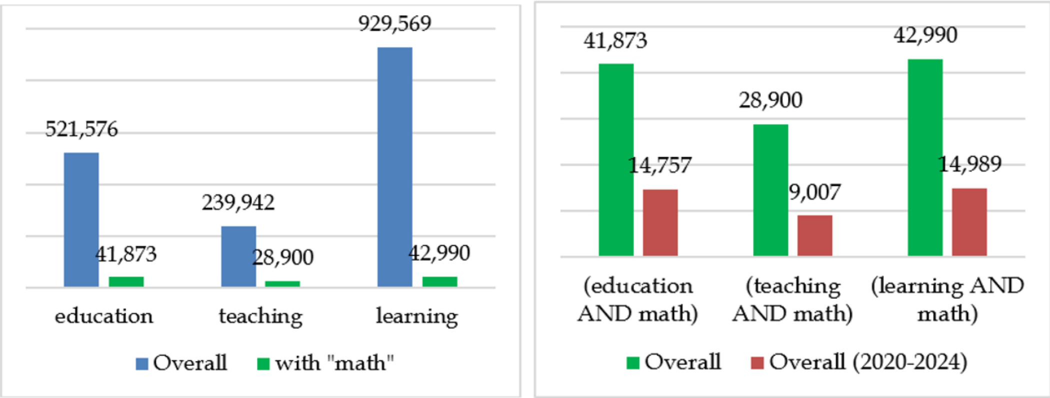
At the same time, the query "education" also has many search results. We explain this by a wide range of objects of study–from pedagogical strategies, specialized teaching methods, and educational reforms to political and social aspects that affect the education system. Such different results for the query "learning" (2.4 billion) and the query "education" (1.6 billion), we explain the increased interest in AI based on machine learning.

Also, we explain the comparatively smaller number of publications for the query "teaching" because such studies mainly focus on the methodological aspects of teaching, which limits their research attractiveness to the general public of scientists.

According to the refined queries A, B, and C for 2020-2024, we expected to find a smaller number of documents. This number is about a third of the total publications for 1970-2024. Among the identified publications, articles prevailed; a much smaller number were proceeding papers and review articles (**Table 2**).

Table 2. Results of clarified queries

Query	Overall (…-2024)	Overall (2020-2024)	2020-2024		
			Article	Proceeding paper	Review article
A	41,873	14,757	12,537	626	1,260
B	28,900	9,007	7,750	296	838
C	42,990	14,989	12,354	659	1,768



(a) In the WoS database as a whole (b) For 2020-2024

Figure 1. Number of publications (total and with the refining of "math" or "mathematics" in the topic field) (Source: Authors' own elaboration)

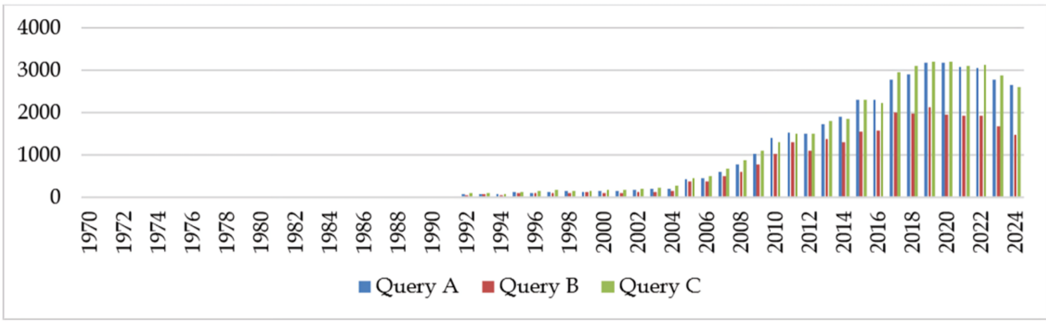


Figure 2. Number of different types of publications in 1970-2024 (Source: Authors' own elaboration)

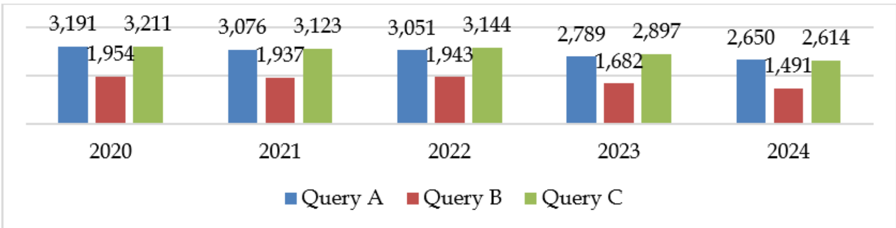


Figure 3. Diagram of the number of publications for refined queries (Source: Authors' own elaboration)

Queries A, B, and C (part a in **Figure 1**) narrow the overall landscape of researchers' scientific research to 5-12% of the previous number of publications. Over the past 5 years, the number of publications amounted to about a third of their total number (part b in **Figure 1**).

The quantitative assessment of publications shows a significant increase by 2019, for example, in 1970-2004 (**Figure 2**). The number of publications was insignificant (less than 700 each year). Since 2005, there has been a rapid increase in the number of studies, which indicates an increase in interest in this topic. The peak of publications was reached in 2019 (n = 8,542), after which their slow decline began (8,356 publications in 2020, 8,136 in 2021, 8,138 in 2022, and 7,368 in 2023). At the beginning of December 2024, the number of publications was 6755.

We recorded such dynamics for the refined queries A, B, and C in different periods (**Figure 3**).

Assessing the quantitative dynamics, we note the almost absence of mathematical education studies in the WoS database until 1990, then a slight increase in the number until 2004 inclusive, after which there was a nearly exponential increase in the number of publications until 2019. The most significant number of

Table 3. Quantitative data on authors and publications (for 2020-2024)

Query	Number of publications for 2020-2024	Number of authors/co-authors in publications	The average number of authors per 1 publication
A	14,757	11,790	0.80
B	9,007	11,127	1.24
C	14,989	12,116	0.81

Table 4. The most productive authors in mathematics education (for 2020-2024)

No	Author	Country (affiliation)	Publications in general	Number of publications on mathematics education	Average citation
1	Lavicza Zsolt	Austria	129	61	5.9
2	Kaiser Gabriele	Germany	164	48	19.4
3	Bouck Emily C.	USA	170	38	14.6
4	Alsina Angel	Spain	205	36	4.1
5	Sarama Julie	USA	136	33	**29.0**
6	Clements Douglas H.	USA	191	32	**29.4**
7	Powell Sarah R.	USA	109	31	26.7
8	Ng Oi-Lam	Canada	46	30	1.6
9	Koenig Johannes	Germany	125	28	25.9
9	Susanne Prediger	Germany	109	28	11.8
9	Jinfa Cai	USA	136	28	16.4
10	Lieven Verschaffel	Belgium	324	26	22.1

publications on the problems of mathematical education was observed in 2019. The dynamics recorded by us, if we recall Price's law, which describes patterns in changes in the number of scientific publications in a particular research field, shows that the development of research in mathematical education has passed the phase of predecessors (1970-2004), the phase of exponential growth (2005-2018), the phase of knowledge consolidation (2019-2022) and is now going through a phase of decreasing activity due to the saturation of scientific topics (Dabi et al., 2016). In other words, the problem of mathematics education has reached its "maturity point" in the sense of saturation of publications and has adapted to changes in technology and public demands.

Authors and Their Cooperation

We conducted a quantitative analysis of the authors of the publications (**Table 3**). According to the queries, the average number of authors per publication is 0.8-1.24. This number indicates that scientists repeatedly touch on the problems of mathematical education and highlight scientific results in several documents.

The top ten most productive authors researching the problems of mathematics education are presented in **Table 4**, which records the number of authors' publications, the average citation per publication, and the country in which the first author is affiliated. Equally productive authors on the subject have the same rating number in **Table 4**.

The most prolific authors are Lavicza Zsolt, who has 61 publications, and Kaiser Gabriele, who has 48 publications after him. All other authors' publications range from 26 to 38 papers. The average number of citations per publication for the top 10 authors ranges from 1.6 to 29.4. The most cited by average estimates are Clements Douglas H. (29.4) and Sarama Julie (29).

We analyzed the structure of cooperation between authors engaged in research on mathematics education using the VOSviewer program. The study includes authors who have at least five collaborative publications on queries. Each network map (**Figure 4**) demonstrates a unique structure in which the relationships between researchers emphasize the role of the first authors in the study of the problems of mathematical education. The size of the circles in the visualization characterizes the number of publications of each author, and the lines between the circles demonstrate the degree of cooperation between them. Different colors indicate author clusters (groups of researchers with the closest ties). This structure allows you to understand patterns of scientific interaction and identify key participants in the cooperation network. The analysis of the submitted networks revealed different structures of cooperation. For query A, seven clusters were identified, uniting 22 authors. The key figure in this network is Kaiser Gabriele, with whom the activities of other researchers are associated (part a in **Figure 4**). Query B made it possible to identify eight clusters covering 40 authors. Among the leading researchers are Lavicza Zsolt, Kaiser Gabriele, Alsina Angel, and Jinfa Cai, around whom connections with other scientists are formed (part b in **Figure 4**). On the web for query C, we found six clusters with 34 authors. The lead researchers are Bouck Emily C. and Powell Sarah R., who are key in establishing scientific collaboration within query (part c in **Figure 4**).

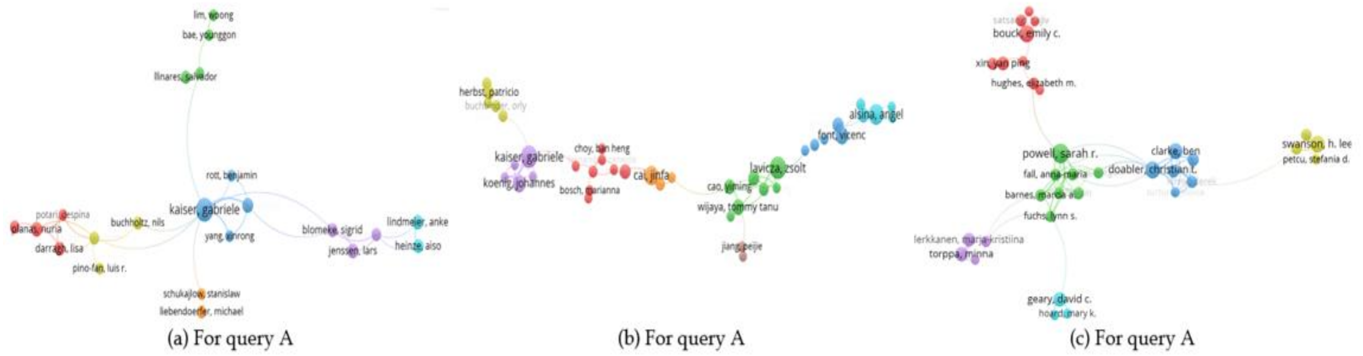


Figure 4. Network map of connections between researchers (Source: Authors' own elaboration)

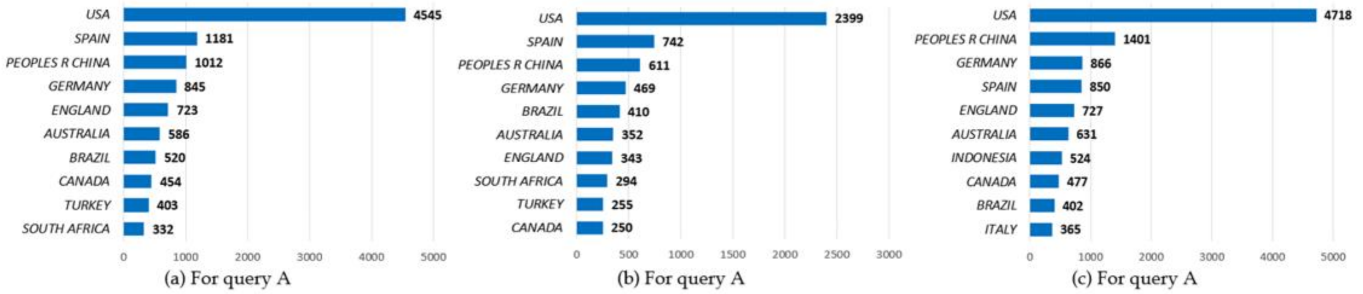


Figure 5. Geographical distribution of publications (top 10 countries) (Source: Authors' own elaboration)

Geographical and Institutional Distribution and Cooperation

To characterize the geographical and institutional distribution, we used only those publications that indicate the authors' affiliation to a specific country or territory or an institution determined by the address indicated in the metadata. At the same time, one author can simultaneously represent several countries or territories, and the publication can be created by authors from different countries or territories. We processed quantitative data in MS Excel.

We discovered that publications on mathematics education issues come from 164 countries or territories. Of these, 46 are located in Europe (28%), in Asia–40 (24.4%), in North America–16 (9.8%), in South America–12 (7.3%), in Africa–38 (23.2%), and 12 (7.3%) in Oceania.

According to the queries, we received the top 10 leading countries regarding the number of studies in mathematics education (**Figure 5**).

A generalization of the results of the analysis shows that the most significant number of publications belongs to authors from the USA (n = 7,399), followed by China (n = 1,901) and Spain (n = 1,499). Economic, social, educational, and demographic factors explain this distribution of countries in the ranking.

We found a network of cooperation (i.e., co-authorship) between countries and territories using VOSviewer, which visualized networks with countries/territories with at least five publications for each query. The program marked the collaboration clusters with different colors. At the same time, the size of the circles reflects the number of publications, and the thickness of the connections demonstrates the strength of collaborations (**Figure 6**).

We have identified several key features of the publication landscape. In the three networks, we observe different patterns of accumulation of international scientific cooperation. For query A, which covers 125 countries, we found three main clusters: around the USA (blue), Spain (green), and Germany (brown). The USA is characterized by close cooperation with South Asia and Oceania countries, such as India, Taiwan, and Indonesia. Spain significantly influences Latin America, forming ties with Chile and Colombia. As the third center, Germany cooperates with European countries, particularly the Netherlands, Italy, and Bulgaria.

We identified seven main clusters: around the USA (pink), around Spain (blue cluster), around Germany (red), around South Africa (blue), around China (green), around Canada (brown), and Sweden (yellow). The USA works closely with South Korea, while Spain has strong ties with Colombia and Chile. Cells around Germany, South Africa, China, Canada, and Sweden show moderate cooperation.

The on-demand B network covers 127 countries and contains seven significant clusters. Most of them around the USA (blue color) include interactions with South Korea, the Philippines, and Rwanda. At the same time, Spain (green) retains ties with Canada, Mexico, Chile, and Portugal, and Germany (blue) forms a European cluster with the Netherlands, Italy, Belgium, and Austria. Significant foci are observed around Indonesia

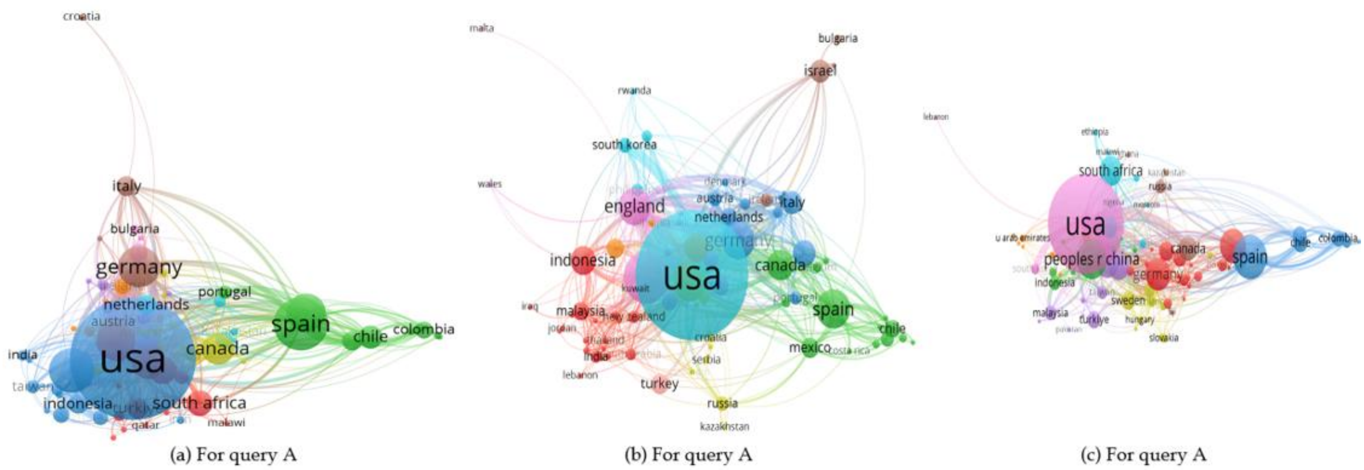


Figure 6. Cooperation networks between countries and territories (Source: Authors' own elaboration)

Table 5. Top 10 most productive institutions by number of publications

No	Query A			Query B			Query C		
	Institution	C	N	Institution	C	N	Institution	C	N
1	University of California System	USA	348	University of California System	USA	152	University of California System	USA	368
2	State University System of Florida	USA	287	State University System of Florida	USA	140	State University System of Florida	USA	283
3	University System of Ohio	USA	225	University System of Georgia	USA	124	PCSHE	USA	255
4	University System of Georgia	USA	218	University of Texas System	USA	122	University of Texas System	USA	233
5	University of Texas System	USA	191	University System of Ohio	USA	107	University System of Ohio	USA	213
6	PCSHE	USA	186	California State University System	USA	102	University System of Georgia	USA	203
7	California State University System	USA	178	University of North Carolina	USA	94	Beijing Normal University	China	181
8	University of North Carolina	USA	174	Michigan State University	USA	88	California State University System	USA	173
9	Beijing Normal University	China	154	PCSHE	USA	87	University of North Carolina	USA	162
10	University of London	UK	142	Beijing Normal University	China	84	University of London	UK	142
10				University System of Maryland	USA	84			

Note. PCSHE: Pennsylvania Commonwealth System of Higher Education; C: Country; & N: Number

(red), Malaysia, India, New Zealand, and Israel (brown color), cooperating with Bulgaria. A separate cluster is the United Kingdom (UK) (pink). Cooperation between Russia, Kazakhstan, Serbia, and Croatia is also traced (yellow).

We found the top 10 most productive institutions (**Table 5**), almost all in the USA.

Among them, the first and second places are occupied by the University of California System (USA) with 868 publications and the State University System of Florida (USA) with 710 publications. This included Beijing Normal University (China) and the University of London (UK). All the institutions in the top 10 are universities, and the Pennsylvania Commonwealth System of Higher Education is an amalgamation of 14 public Pennsylvania state universities in the USA.

Citation Analysis

One of the most significant aspects of the publication landscape is citation analysis, which allows you to identify precisely how scientific advances are used in further research and how citations stimulate new hypotheses, approaches, or methods that influence scientific trends (Li & Hale, 2016). This allows the discovery of critical scientific artifacts and works that have significantly contributed to forming new scientific schools or paradigms. Citation evaluation allows for a deeper understanding of scientific papers' local and global impact, which is necessary to form scientific strategies and policies.

We recorded the five most cited publications for 2020-2024 (**Table 6**).

Table 6. Top 5 most cited publications (for 2020-2024)

Query	Document title	Authors (year)	N
A	Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math	Theobald et al. (2020)	546
	Projecting the potential impact of COVID-19 school closures on academic achievement	Kuhfeld et al. (2020)	464
	Motivation and social cognitive theory	Schunk and DiBenedetto (2020)	453
	What is the impact of ChatGPT on education? A rapid review of the literature	Lo (2023)	391
	Mapping research in student engagement and educational technology in higher education: A systematic evidence map	Bond et al. (2020)	303
B	Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math	Theobald et al. (2020)	546
	Teacher job satisfaction: The importance of school working conditions and teacher characteristics	Toropova et al. (2020)	251
	Interacting with educational chatbots: A systematic review	Kuhail et al. (2023)	176
	Why lockdown and distance learning during the COVID-19 pandemic are likely to increase the social class achievement gap	Goudeau et al. (2021)	170
	Facilitating student engagement through the flipped learning approach in K-12: A systematic review	Bond (2020)	164
C	Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math	Theobald et al. (2020)]	546
	Projecting the potential impact of COVID-19 school closures on academic achievement	Kuhail et al. (2023)	464
	Artificial intelligence: A powerful paradigm for scientific research	Xu et al. (2021)	439
	What ChatGPT and generative AI mean for science	Stokel-Walker and Van Noorden (2023)	318
	Mapping research in student engagement and educational technology in higher education: A systematic evidence map	Bond et al. (2020)	303

Note. N: Number of citations

Scientific publications with the most citations are submitted by scientists affiliated with the USA (three publications), China (two publications), and one paper each from Germany, Sweden, France, the UK, and the United Arab Emirates.

"Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math" by Theobald et al. (2020), which has been cited 546 times since 2020. The second most cited (464 times) for A and B queries is the article "Projecting the potential impact of COVID-19 school closures on academic achievement" by Kuhfeld et al. (2020), published in 2020. At query B, the second place is taken by the publication "Teacher job satisfaction: The importance of school working conditions and teacher characteristics" by Toropova et al. (2020) released in 2020 with 251 citations. The objects of research of the most cited publications are the impact of the latest technologies on the educational achievements of students, the need to adapt teaching methods, social and ethical aspects of the integration of students into the educational process, ethical aspects of the use of technologies; the impact of technology on pedagogical practices and professional development of teachers; potential challenges and benefits of mathematics education for different social groups. According to query C, we identified publications that explore the use of AI (third and fourth places with 439 and 318 citations, respectively).

Keyword Analysis (Publications 2020-2024)

Keywords act as semantic indicators that reflect the main content of articles and are the basis for forming thematic clusters. Their analysis allows you to assess the thematic structure of scientific publications and identify key research areas in a particular field. For multiple posts for each query, we left keywords based on their repetition in at least 50 posts and used the VOSviewer program to build keyword networks. For each of the queries A, B, and C, the most used keywords are written out, and a description of the research objects related to these keywords is given.

For query A, we recorded 12,744 unique keywords in all publications, identified only 93 keywords used in at least 50 publications, and grouped them into four clusters (**Table 7**).

The red cluster focuses on three key areas: professional development of teachers, integration of pedagogical innovations, and improvement of curricula. These topics reflect new strategies for teaching mathematics through the renewal of approaches to teacher training. The green cluster focuses on studying psychological factors that affect students' mathematical achievements.

Table 7. Qualitative description of clusters for query A

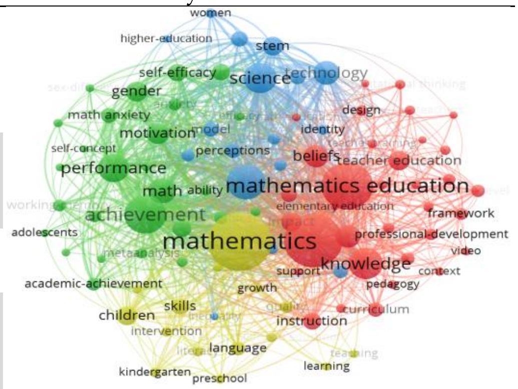
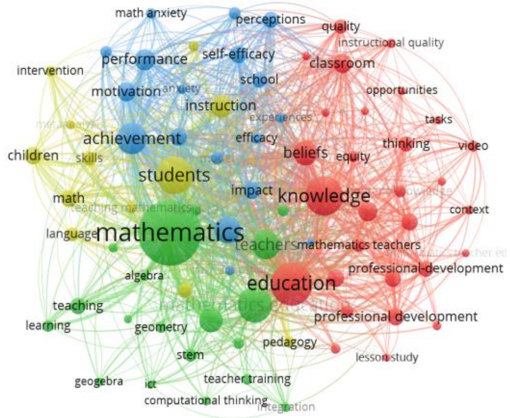
<table>
<tr><th>Color</th><th>Generic name</th><th>Main keywords</th><th>Keyword network</th></tr>
<tr><td>Red</td><td>Mathematics teacher training</td><td>mathematics education, knowledge, education, teacher, framework, beliefs, professional development, pedagogy, instruction, curriculum, etc.</td><td rowspan="4"></td></tr>
<tr><td>Green</td><td>Psychological aspects of mathematical performance</td><td>achievement, math, performance, motivation, gender, self-efficacy, math anxiety</td></tr>
<tr><td>Blue</td><td>STEM education</td><td>science, STEM, technology, perceptions, identity</td></tr>
<tr><td>Yellow</td><td>Early math training</td><td>mathematics, children, skills, growth, language, kindergarten, preschool, intervention, learning</td></tr>
</table>

Table 8. Qualitative description of clusters for query B

<table>
<tr><th>Color</th><th>Generic name</th><th>Main keywords</th><th>Keyword network</th></tr>
<tr><td>Red</td><td>Pedagogical practices of teaching mathematics</td><td>education, knowledge, beliefs, classroom, quality, tasks, video, equity, mathematics teachers, professional development, pedagogy, etc.</td><td rowspan="4"></td></tr>
<tr><td>Green</td><td>Computational thinking and STEM</td><td>mathematics, teachers, teaching, learning, teacher training, algebra, geometry, STEM, computational thinking, integration, GeoGebra</td></tr>
<tr><td>Blue</td><td>Psychological aspects of teaching mathematics</td><td>achievement, motivation, impact, performance, self-efficacy, math anxiety, perceptions, school, experiences, etc.</td></tr>
<tr><td>Yellow</td><td>Math teaching methods and skills</td><td>students, instruction, children, skills, math, language, intervention</td></tr>
</table>

These areas are essential for overcoming barriers and improving academic performance. The blue cluster covers topics related to STEM, the introduction of technological innovations in the educational process, and the formation of scientific thinking. This cluster reflects the current trend of integrating technologies and innovations into the education system to prepare students to solve complex interdisciplinary problems. The dark yellow cluster focuses on three main areas: children's mathematical development, interactive teaching methods, and adaptation of preschool educational practices. The theme of this cluster emphasizes the importance of early formation of mathematical skills, which are the basis for further successful learning.

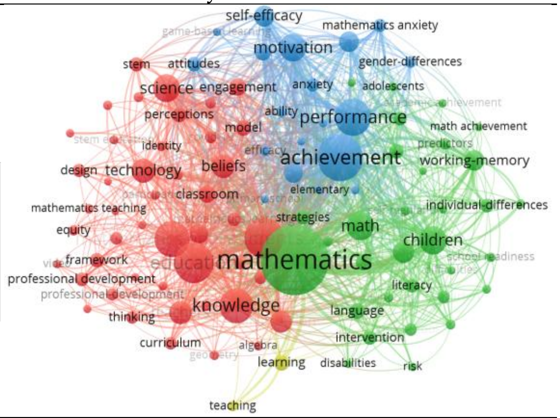
Query B identified 12,365 unique keywords, of which 78 are used in at least 50 publications and are grouped into four clusters (**Table 8**).

The red cluster covers topics related to pedagogical practices and the organization of studio lessons. These areas emphasize the importance of improving the skills of teachers and introducing innovative approaches to the educational process. The green color cluster focuses on computational thinking and teachers' activities in teaching mathematics. The cluster covers the problems of STEM implementation and the development of computational thinking. The blue cluster focuses on the psychological aspects of teaching mathematics: students' motivation, self-esteem, mathematical anxiety, and perception of learning outcomes. These factors are essential for creating a favorable educational environment that stimulates academic development and forms a positive attitude toward learning. The dark yellow cluster emphasizes the importance of using effective methods of teaching mathematics. It covers topics related to the development of skills, the language of instruction, and the analysis of various interventions in teaching mathematics.

For query C, we found 13,111 unique keywords, of which 99 appear in at least 50 posts. As a result of keyword analysis, we identified three main clusters (**Table 9**).

The red cluster includes STEM education, technological innovation, and pedagogical design topics. The cluster emphasizes the importance of integrating science, modern technologies, and the development of thinking in mathematics education. The green cluster focuses on individual student differences and intervention programs aimed at developing mathematical literacy and supporting children with learning difficulties. This cluster highlights the importance of adapting educational approaches to the

Table 9. Qualitative description of clusters for query C

Color	Generic name	Main keywords	Keyword network
Red	Technology, educational design, STEM, and mindset	knowledge, technology, beliefs, model, equity, curriculum, classroom, science, framework, attitudes, professional development, STEM, engagement, thinking, etc.	
Green	Individual characteristics and support in teaching mathematics	mathematics, children, working memory, language, intervention, math achievement, predictors, individual differences, strategies, literacy, disabilities, etc.	
Blue	Psychological factors and gender differentiation	achievement, performance, motivation, self-efficacy, gender differences, math anxiety, ability, etc.	

needs of each student, especially those who face learning barriers. The blue cluster covers motivation, understanding anxiety, and gender differences. It demonstrates that students' emotional state, interest in the subject, and interactive approaches significantly impact math performance.

The analysis of word networks for three queries allowed us to identify generalized trends in modern research in the field of mathematics education:

(1) modern strategies and design in mathematics education,

(2) individual support of students, their motivation, self-esteem, and emotional state in the process of teaching mathematics,

(3) interdisciplinary approaches in mathematics education, including STEM,

(4) training of mathematics teachers and their professional development,

(5) the development of skills and thinking in mathematics education,

(6) equality in the teaching of mathematics, which includes bridging educational gaps and gender equality, and

(7) early mathematical education.

DISCUSSION

We used bibliometric analysis to characterize the publication landscape and found that research in mathematics education is significant in number and diverse in subjects. In general, the authors of review studies use various quantitative methods, including bibliometric analysis (Bakker et al., 2021; Drijvers et al., 2020), meta-analysis (Wahono et al., 2020), cluster analysis (Mulenga & Marbán, 2020), as well as regression analysis (Kania et al., 2024). These methods provide information about various aspects of the publication landscape. However, only bibliometric analysis allows you to identify research trends by keywords and evaluate the productivity and significance of research, which is especially important in mathematical education. Thus, we found that the most significant number of publications on the problems of mathematics education was observed in 2019. This is due to several factors. Firstly, it is during this period that a significant number of international initiatives (for example, awareness of the results of PISA 2018) are accounted for, aimed at increasing the level of mathematical literacy of young people. Secondly, it may be related to the popularization and development of STEM education and increased interest in interdisciplinary research, where mathematics is a key tool for analysis and modeling. Therefore, the peak of publications in 2019 can be considered as the result of a long preparation of educational systems for the challenges of digital transformation and the growing role of mathematics as a fundamental scientific and academic discipline of the modern world. The transition to distance learning during the COVID-19 pandemic (2020-2021) has impacted on the number of studies (in 2020-2021, the number of publications decreased). It is likely that led to the search for new approaches to obtaining mathematical education in the context of new restrictions (distance learning, blended and mobile learning), actualized the problem of inequality in mathematics education and the issue of the digital divide, the emergence and spread of digital tools for interactive teaching of mathematics, the development of new strategies for online education, and the spread of digital educational resources.

The geographical distribution of publications on mathematical education problems indicates scientists' activity in such countries as the USA, China, Spain, Germany, England, Indonesia, South Africa, and Turkey. The leadership of the USA, China, Spain, Germany, and England is driven by their economic stability, investment in education, and scientific traditions. In developing countries such as Indonesia, South Africa, and Turkey, the development of mathematics education is stimulated by the growing demand for STEM technologies, international cooperation, and support. Li and Tang (2024) identify the USA as a leading country in mathematics education research. Konur and Keskin (2022) found that the UK, Germany, Australia, China, Mexico, and Spain make significant contributions related to the use of augmented reality in mathematics education. Wahyuni et al. (2025), considering trends in mathematical anxiety research, cite Italy (University of Barcelona) as a leader in this field. The geographical distribution of publications reveals the dispersion of scientific research in different countries and regions. This emphasizes, on the one hand, the similarity of problems in mathematical education and, on the other hand, reveals the local social dependence of mathematics education research on curricula in a particular region. Therefore, we see the need to strengthen research capacity building in the underrepresented areas to ensure more equitable access to knowledge and resources. These and the results we obtained highlight the need for international cooperation to promote knowledge sharing and solve global problems in mathematics education.

The number of citations of a publication is primarily correlated with the time that has elapsed since its publication (Qui & Chen, 2009). For the period 1970-2024, the most cited article (4,166) for all queries is the article "Active learning increases student performance in science, engineering, and mathematics" by Freeman et al. (2014) published in the "Proceedings of the National Academy of Sciences of the United States of America" in 2014. The first author is affiliated with the University of Washington, Seattle. Over the past five years, Theobald et al. (2020) and Kuhfeld et al. (2020) publications have been the most cited, with 546 and 464 citations, respectively. The publications with the most significant citations were published in various scientific journals. This indicates both a wide range of platforms for publishing research results and a wide distribution of attention of the scientific community among different publishers. The objects of research of the most cited publications were the impact of the latest technologies on the educational achievements of students, the need to adapt teaching methods, social and ethical aspects of technology integration, the impact of technology on pedagogical practices, and the professional development of teachers. The listed areas are identified as popular in other review publications: in the article (Subroto et al., 2024), the authors, based on the analysis of data from the Scopus database, confirm the growing interest in the use of AI as a tool for teaching mathematics and identify the USA and China as leaders in the number of publications and citations; in the article (Li & Tang, 2024) researchers of WoS publications for 2013-2023 in the context of the words "mathematical education and development" identified leading trends (professional development of teachers, mathematical education and training, preschool education, assessment of learning outcomes) and leading countries in the formation of global trends in mathematics education–the USA, England, Germany, Australia and China; in the article (Dasari et al., 2024), researchers based on the materials of the Scopus database traced the trends in the development of mathematical competencies, technology integration, e-learning, the use of augmented reality and STEM; in the article (Cevikbas et al., 2024) Scientists, according to data from WoS, found consonant current trends–digital technologies, teacher training, achievements in mathematics and learning difficulties, but our work indicates a broader trend, including research on motivational and emotional factors that affect mathematics learning.

At the same time, our work has an authentic contribution; in particular, among the key trends today, we note trends in the development of thinking in mathematics education, equality in mathematics education, and early mathematics education. These trends are not indicated in review publications. Research on high-level thinking skills (analysis, synthesis, comparison, generalization, evaluation, forecasting, etc.) in mathematics education correlates with 21st century skills (van Laar et al., 2017). Therefore, we consider studies that will give a clear idea of how to effectively integrate/predict the development of thinking in mathematics curricula and the development of methods and techniques for assessing their development in students.

The problem of equality in teaching mathematics is raised in different contexts. Still, it has become relevant with the ultra-rapid development of IT, social changes in other countries, the transition of learning to an online or mixed format, etc. Therefore, we consider the study of the problems of the gap in educational achievements in the context of certain limitations: technological (lack or insufficient access to the Internet; limited use of digital devices; insufficient digital literacy of students or teachers; lack of specialized software), physical (learning in conditions of military conflicts or crisis situations; absence or destruction of educational institutions; limited access to libraries, laboratories, educational materials); psychological (stress and anxiety due to an unstable situation (war, pandemic, social crises); exhaustion due to changes in the format of learning (online, offline, and mixed); motivational problems due to lack of socialization); social and economic (financial difficulties (inability to purchase equipment, pay for the Internet or educational materials), inequality in access to quality education (rural regions, socially vulnerable groups), outflow of personnel and lack of qualified teachers); organizational (transition to distance learning without proper preparation; lack of methodological materials for adaptation to new formats of learning/teaching), lack of effective control over the educational process).

Early mathematical education, in our opinion, has become a key trend due to the actualization of the problem of thinking development, for which preschool age is key. Akulenko (2024) confirms the impact of early mathematical education on the child's further academic success, and the availability of digital technologies and EdTech tools allow the development of mathematical skills from an early age (Thai et al., 2023). Therefore, we see promising areas of research in the field of early mathematical education: game methods of teaching mathematics; the use of mobile applications, VR/AR, and adaptive educational software (for example, GeoGebra) for the assimilation of mathematical concepts by children; exploring the relationship between early mathematical literacy and future academic success; comparison of models of early mathematics education in different countries and their effectiveness; the relationship between mathematical and other types of literacy (language, reading, digital).

Restriction

We must note the limitations that are imposed on the results we obtain.

The last update of the WoS database at the time of the search (December 3, 2024) occurred on December 2, 2024. After that, the database changed: publications were added, and possibly, publications were excluded. Therefore, repeating the exact search on another day may give different results.

The result we obtained depends on the specific scientific metric database. Therefore, the results of bibliometric analysis may limit the distribution and generalization of conclusions.

Many publications in the authorship analysis could lead to unavoidable calculation errors. In particular, we could not separate authors with the same names and combine them into a single record of those published under different names (for example, due to a change of surname).

We note the emphasis on the last 5 years of the publication landscape and a cursory analysis of long-term trends driving changes in the overall landscape of research in mathematics education. The five-year period limits the understanding of the evolution of research topics. It approaches overtime and, at the same time, allows you to identify current trends influenced by the development of IT.

We have limited attention to the problems of inclusiveness in mathematics education. We believe that separate studies of social, economic, demographic, gender, etc., are needed in the context of the stated research problem.

CONCLUSIONS

We conducted a study based on publications on mathematics education published in the WoS database between 2020 and 2024. Our description of the publication landscape showed a rapid increase in the number of studies since 2005, with a maximum in 2019, after which a gradual decline began. The share of publications related to mathematics education is about 5% of the total number of studies in the field of education, which indicates a relatively narrow specialization in this area. The analysis of the authors' performance showed that the most active researchers are Lavicza Zsolt and Kaiser Gabriele, and the collaboration between the authors reveals different patterns of relationships that depend on various factors (economic, historical, geopolitical, etc.). The leading countries in this area remain the USA, China, and Spain, which confirms their leading positions in forming global research trends.

The analysis of the most cited publications showed that studies with high scientific significance were published by various platforms, which confirms the interdisciplinary nature of mathematics education. Key areas of research were identified (modern strategies and design in mathematics education; individual support of students, their motivation, self-esteem, and emotional state in the process of teaching mathematics; interdisciplinary approaches in mathematics education, including STEM; training of mathematics teachers and their professional development; development of skills and thinking in mathematics education; equality in the teaching of mathematics, which includes bridging educational gaps and gender equality; early mathematical education), form modern vectors of industry development. The results obtained by us are consistent with previous research and supplement them with new ideas about the dynamics of the development of mathematical education, which can become the basis for creating more adaptive and effective educational systems that can meet modern challenges.

Also, the results obtained provide the basis for forecasting promising scientific research. An integrated approach (bibliometric analysis with detailed qualitative research) is necessary for a comprehensive and deep understanding of mathematical education's dynamism under the influence of the IT industry. Future research should focus on exploring the role of new IT (in particular, machine learning, AI, and augmented reality technologies) in training mathematics teachers and developing mathematics education strategies and approaches to mathematics teaching and learning. We also consider promising longitudinal studies that allow you to track the development of mathematical knowledge and skills over time to identify the impact of various pedagogical innovations on the mathematical training of students of different ages and genders, study the effectiveness of multiple strategies for evaluating mathematical knowledge; research to identify factors that cause mathematical anxiety in students and factors that can reduce it in different groups of students (age, gender, etc.); study of the problems of the development of thinking in the process of teaching mathematics and the gap in educational achievements under certain restrictions of different groups of students.

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