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Measurement Analysis and Evaluation of Twenty-Five Years of Mathematics Education Research in China: Visual Econometric Analysis Based on CiteSpace Knowledge Mapping (1999–2024)

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Abstract: Since the new century, China's mathematics curriculum reform in basic education has continued to move forward in attempts and explorations, presenting many new changes, trends, movements, and developments. Sorting out, analyzing, and summarizing the achievements, experiences, problems, and challenges in this journey are conducive to providing insights for the reform and development of the Chinese basic education mathematics curriculum in the new era. This paper analyses the research on mathematics education in China (1999–2024) using the visual measurement of CiteSpace knowledge mapping, hoping to provide directions for the future of mathematics education in China.

Keywords: Mathematics education; Visual econometric analysis; CiteSpace

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1. Introduction

Since 1949, the development of mathematics education in China has had a history of more than 70 years, and has gone through the process of "completely copying-absorbing-borrowing-forming a mathematics education system with Chinese characteristics" [1]. In recent times, compared to the West, there has been a gap in the overall level of mathematics education research in China [2]. At the same time, the existing research mainly relies on high-frequency keywords to analyze the current situation of international research [3], focusing on the characteristics and hotspots of research on mathematics education in China [4]. China's mathematics education is at a new historical starting point, and a visual analysis and study of China's mathematics education over the past 25 years in terms of keywords, issuing authors, and issuing institutions will certainly enlighten mathematics education in the new era.

2. Methods

CiteSpace visual econometric analysis is a commonly used research tool in the field of bibliometrics, which

is able to conduct econometric analysis of the literature collection of a specific topic, and form a basic understanding of the development status, hotspot evolution, and future trends of this research field with the help of visual knowledge mapping. In this paper, we used CiteSpace software version 6.3.R1, selected "CSSCI (China Social Science Index)" database with high recognition from China National Knowledge Infrastructure (CNKI) as the source of literature retrieval from 1999–2022, and adopted the search logic of "theme = mathematics education" to eliminate invalid information such as conferences, column introduction, news notice, journal catalog, new book recommendation, etc., and a total of 1,000 journals were finally obtained.

3. Results

3.1. The annual trend of issuing documents

The inter-annual changes in the number of articles can reflect the research popularity of a specific topic at a specific time, and show the development of the research topic as a whole. The annual statistics of journal articles in the CNKI database are made into the annual publication statistics of China's mathematics education research (**Figure 1**). From the table, it can be seen that the overall trend of China's mathematics research results is as follows, with a fluctuating trend from 1998 to 2013, and a sudden increase in the annual publication volume in 2014, followed by a gradual stabilization.

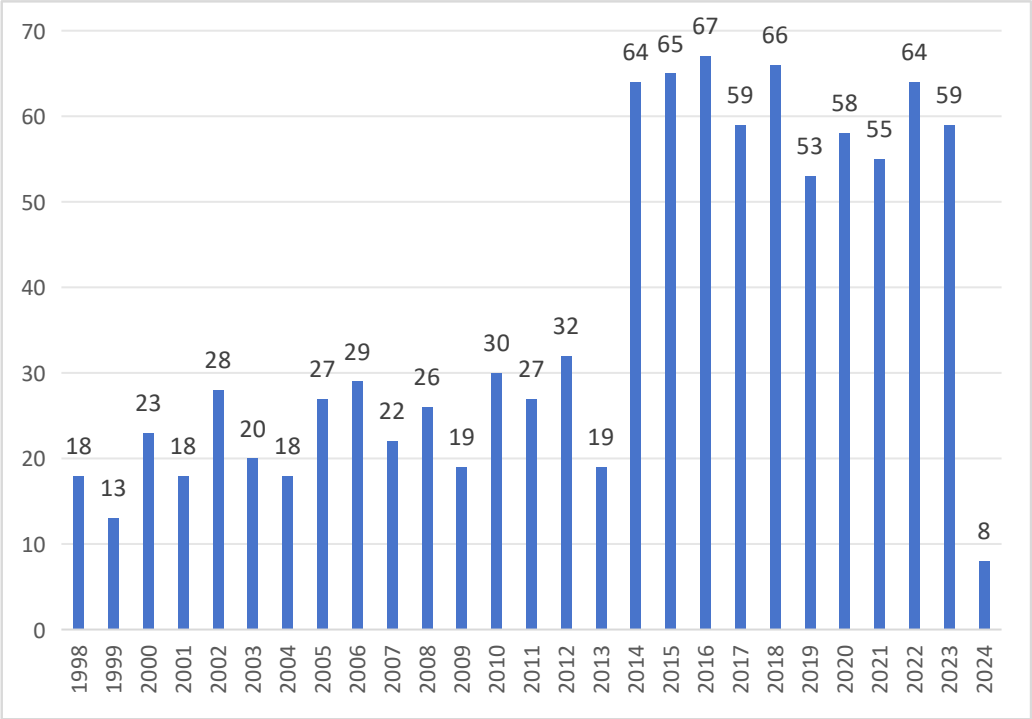

Figure 1. Annual publications on mathematics education research in China

3.2. The distribution of research power

3.2.1. Analysis of research institutions and their groups

In order to make accurate statistics on this, this thesis adopted Price's law to count the research results published in core institutions, and the corresponding formulas are as follows: $N \approx 0.749 \times \sqrt{Nmax}$ where the letter N is the minimum number of papers published by the core author units, and Nmax is the number of papers published by the most productive author units. According to the statistics of Zhi.com.cn, there are 478 colleges and universities participating in the research of Chinese mathematics textbooks between 1999 and 2024, among

which the highest number of papers published is 41 by the School of Mathematics and Statistics of Southwest University (**Table 1**), i.e., Nmax = 41, which is calculated by substituting the formula, N ≈ 4.79, rounding up to the nearest five, and combining with the results of the calculations. It can be concluded that the research institutes that have published five or more papers can be defined as core author units, and those that have published more than five papers can be classified as core author units. The statistical results are shown in **Table 1**.

Table 1. Institutional table of core authors

No.	Frequency	Centrality	Year	Institutions
1	41	0.03	2018	School of Mathematical Sciences, East China Normal University
2	40	0.02	2008	School of Mathematics and Statistics, Southwest University
3	32	0.02	2017	Teacher Education College of East China Normal University
4	27	0.01	2002	East China Normal University
5	25	0.01	2005	School of Mathematical Sciences. Beijing Normal University
6	19	0	1999	Department of Philosophy, Nanjing University
7	16	0	2011	School of Mathematics and Statistics, Central China Normal University
8	16	0	2013	Teacher Education College of Tianjin Normal University
9	15	0	2001	Institute of Curriculum and Teaching at East China Normal University
10	15	0.01	1998	East China Normal University
11	13	0	2015	Inner Mongolia Normal University Institute of Science and Technology History
12	12	0	2016	Shanghai Key Laboratory of Core Mathematics and Practice
13	12	0.04	2014	Beijing Normal University China Basic Education Quality Monitoring Collaborative Innovation Center
14	11	0	2014	School of Education Northwest Normal University
15	11	0.01	2014	School of Mathematics and Statistics, Northeast Normal University
16	11	0	2011	School of Mathematical Sciences, South China Normal University
17	10	0.01	2004	Northeast Normal University
18	10	0.01	2012	Education Department of Northeast Normal University
19	10	0	2008	School of Teacher Education, Zhejiang Normal University
20	10	0.01	2000	School of Education Science, Northeast Normal University
21	9	0.01	2011	Jilin Normal University School of Mathematics
22	8	0.01	2010	Education Department of Beijing Normal University
23	8	0	2015	School of Science, Central University for Nationalities
24	8	0	2018	Education College of Tangshan Normal University
25	7	0.02	2010	Southwest University
26	7	0.01	2010	Basic Education Research Center of Southwest University
27	7	0	2010	School of Mathematics and Information Science, Guangzhou University
28	6	0	2009	School of Education Shanghai Normal University
29	6	0	2013	Beijing Institute of Educational Sciences
30	6	0	2017	School of Mathematical Sciences, Guizhou Normal University
31	6	0	1999	Beijing Normal University

Table 1 (Continued)

No.	Frequency	Centrality	Year	Institutions
32	6	0	2015	Institute of Curriculum and Teaching at Nanjing Normal University
33	6	0	2016	School of Education, Central South University for Nationalities
34	6	0	2015	Shanghai Normal University Institute of International and Comparative Education
35	5	0	2013	School of Mathematics and Information Science, Wenzhou University
36	5	0	2018	China Basic Education Quality Monitoring Collaborative Innovation Center Southwest University Branch
37	5	0	2018	Education Department of East China Normal University

Statistics show that a total of 478 institutions are involved in the research of mathematics teaching materials in China, of which 37 are core research institutions. The number of articles issued by institutions shows that the School of Mathematical Sciences of East China Normal University (41 articles) is in the absolute leading position in the field of mathematics education research in China.

On the whole, the main research institutions of mathematics education in China are dominated by the major teacher-training colleges and universities (**Figure** 2). Clustering the author units with CiteSpace knowledge graph, we can see that the specific directions of research in different institutions are also different. The Institute of International and Comparative Education at Shanghai Normal University focuses on "#6 Intercultural Communication," the School of Teacher Education at Central China Normal University focuses on "#7 High School Mathematics Teachers," and the School of Mathematical Sciences at Beijing Normal University focuses on "#4 Core Literacy" (**Figure 3**).

A left-to-right, bottom-up map of the evolution of mathematics education and research institutions is presented (**Figure 4**). Among them, Huazhong Normal University and Shanghai Core Mathematics and Key Laboratory focus on "icmi-14," ICMI series of research activities began in the mid-1980s, focusing on current topics of interest or special significance in mathematics education, and convening international symposiums organized by leading scholars and practitioners in the field [5] and the publication of independent research volumes (see https://www.springer.com/series/6351 for the new ICMI research series of publications), aiming to provide coherent, state-of-the-art research findings in the field.

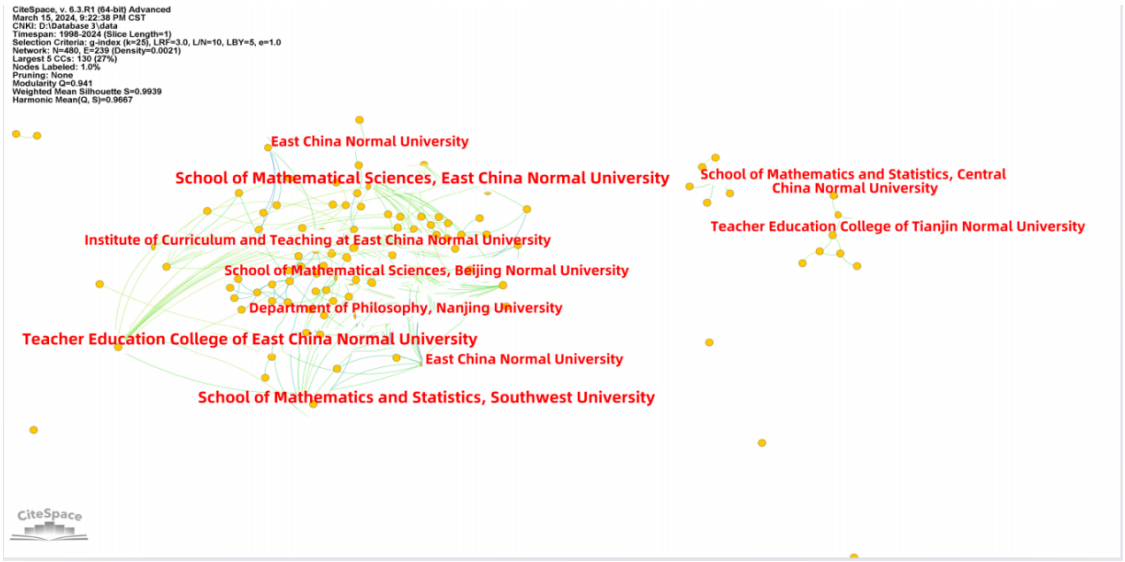

Figure 2. Author's institutional chart

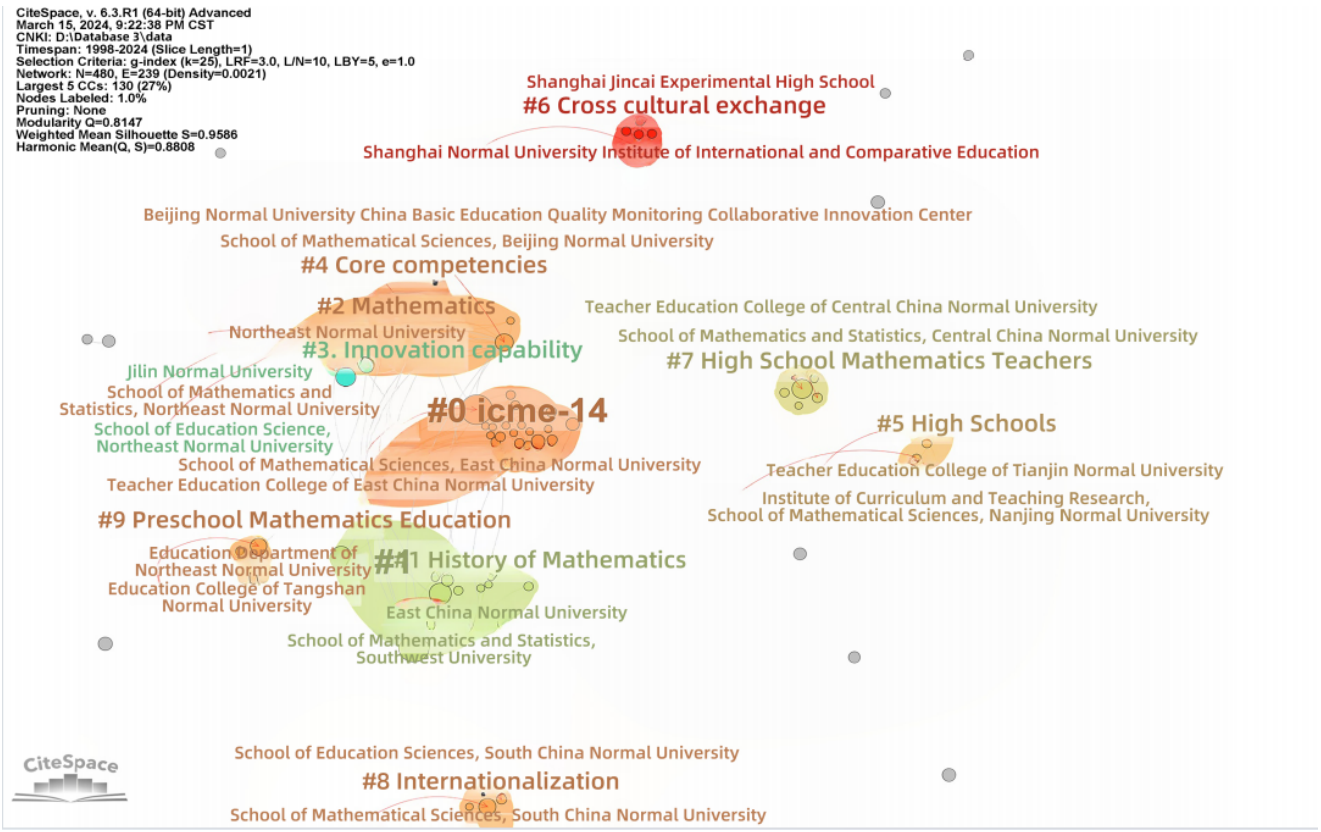

Figure 3. Clustering diagram of author organizations

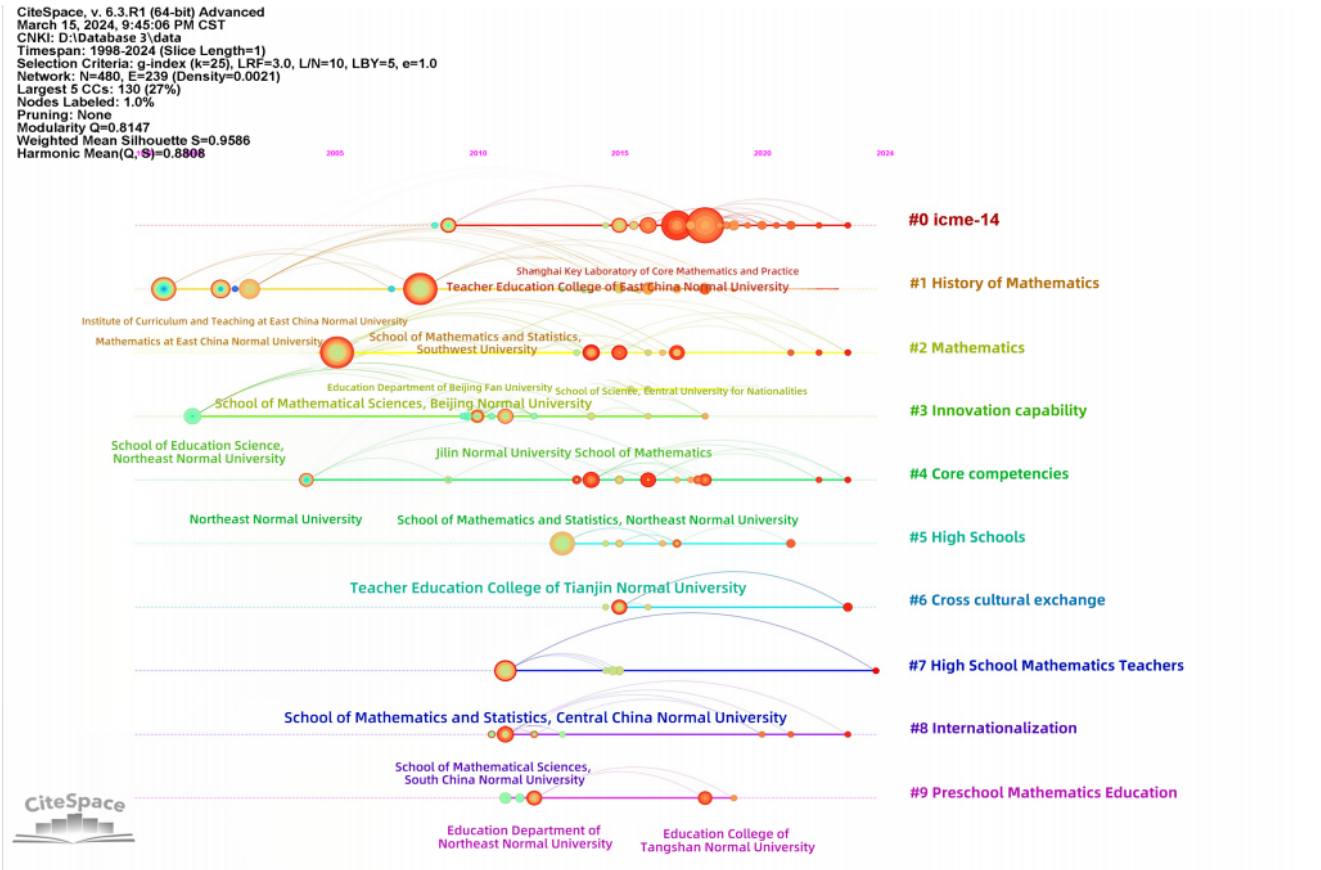

Figure 4. Map of time zones of sending institutions

3.2.2. Analysis of published authors

In order to present the core authors in the field of mathematics education research clearly and accurately, the determination of the core authors in this subject area was also calculated using Price's Law, i.e., $M \approx 0.749 \times \sqrt{Nmax}$. In the formula, the letter M means the minimum number of articles published by the core authors, and Nmax indicates the number of articles published by the author who publishes the most articles. According to the statistics on the platform Knowledge.com, the author who published the most articles on the sociology of education during the period of 1999–2024 is Naiqing Song, whose number of articles is 24 (**Table 2**). Substituting Nmax = 24 into the formula, we get the result, i.e., $M \approx 3.66$, which is rounded up to 4 research results. The following conclusion is drawn: 4 or more publications in the field of mathematics education in China can be defined as core authors, as shown in **Table 2**. Clustering the authors with CiteSpace knowledge graph, it can be obtained that the specific direction of research of different authors is also different (**Table 2**, **Figure 5**).

Table 2. Authors of core publication

No.	Frequency	Year	Author	No.	Frequency	Year	Author
1	24	1998	Naiqing Song	21	5	2015	Hengjun Tang
2	23	2004	Ningzhong Shi	22	5	2021	Lianchun Dong
3	17	2005	Yiming Cao	23	4	2014	Jianchuan Lu
4	15	1998	Binyan Xu	24	4	2010	Jian Liu
5	14	2014	Qin Dai	25	4	2006	Xiaogang Xia
6	13	1999	Yuxin Zheng	26	4	2005	Xiaohong Wu
7	12	2004	Fanzhe Kong	27	4	2016	Weizhong She
8	12	1999	Guangming Wang	28	4	2011	Caibin Tang
9	10	2018	Jiansheng Bao	29	4	2011	Dasheng Shi
10	9	2004	Xiaoqin Wang	30	4	2017	Yingkang Wu
11	9	2005	Weizhong Zhang	31	4	2020	Silu Liu
12	8	1998	Qiping Kong	32	4	2012	Pengfei Liu
13	8	2013	Zhangtao Xu	33	4	2011	Lin Chu
14	7	2014	Shihu Lv	34	4	2014	Nan Zhang
15	7	2014	Hong Yan	35	4	2006	Chuanhan Lv
16	7	2016	Bin Xiong	36	4	2013	Youchu Huang
17	7	2001	Wenfang Zhu	37	4	2001	Dingqiang Zhang
18	7	2000	Yunpeng Ma	38	4	2016	Yijie He
19	6	2018	Liming Zhu	39	4	2005	Lijuan Pang
20	5	2019	Wei He				

Figure 5. Map of authors of communications

Clustering the authors using the CiteSpace knowledge graph reveals that the specific directions of different authors vary. Hongming Yan focuses on "#1 International Assessment," Fanzhe Kong focuses on "#2 Teaching and Learning," and Wei He and Lianchun Dong focus on "#6 Cultural Activities," as shown in **Figure 6**.

Figure 6. Clustering of authors of publications

3.3. Research results and content analysis

The extraction and condensation of the main content of the paper are the keywords, and the keywords can also present the main academic views and ideas of the author's article. The tracking of keywords can be a good way

to grasp the development path and development status of related literature research objects. Clicking on "Node Types": Keyword can obtain a clear visualization result, and the knowledge map of the main keywords is shown in **Figure 7** below.

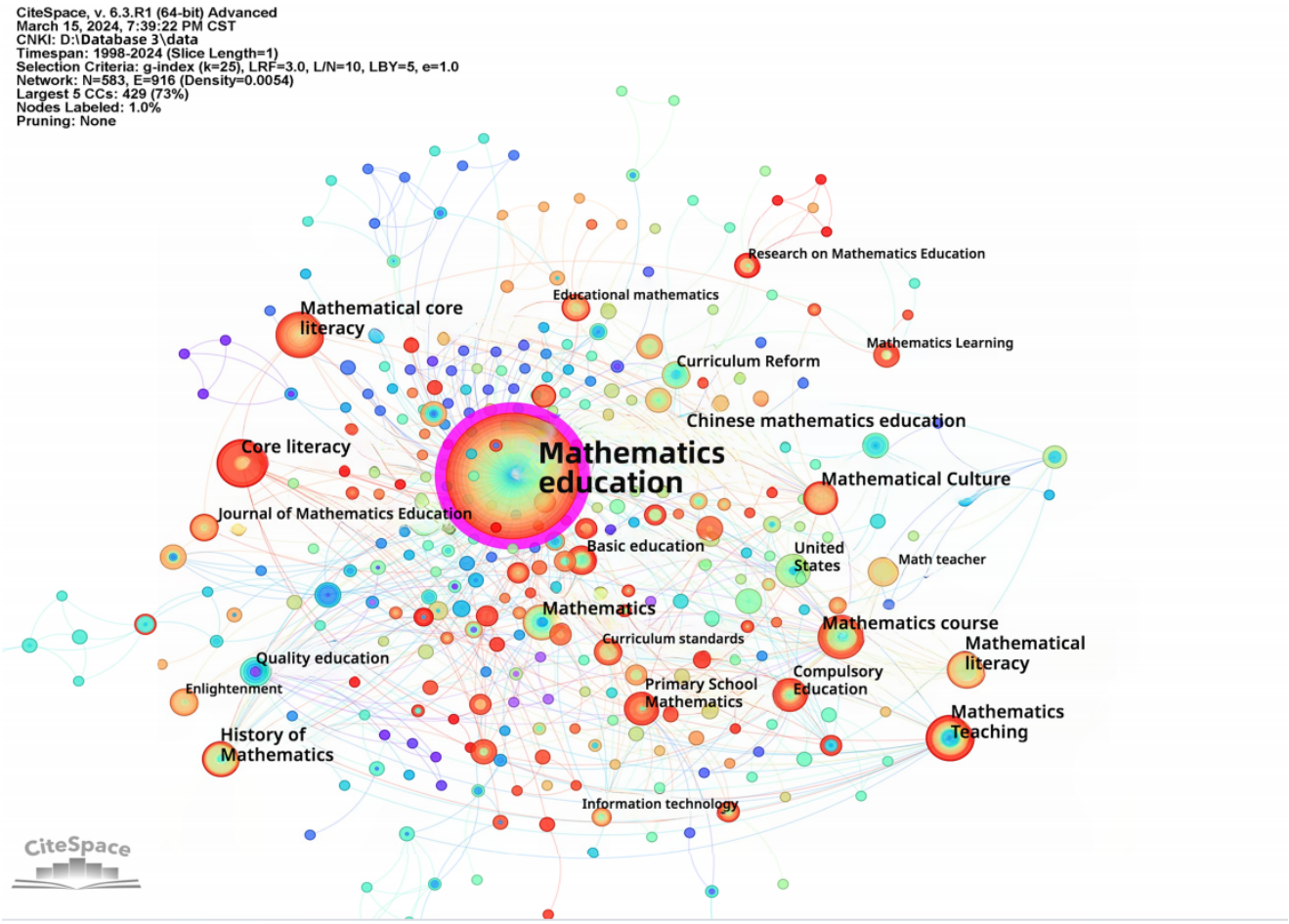

Figure 7. Keyword co-occurrence map

As can be seen in **Figure 7**, 583 nodes (keywords) and 916 connecting lines (co-occurrence relationships) were obtained. In order to enhance the credibility and scientificity of the study, this paper still adopted Price's law, i.e. $M \approx 0.749 \times \sqrt{Nmax}$. In the formula, the letter M means the lowest frequency of the core keywords, and Nmax means the highest frequency of the keywords. According to the statistics on the platform of Knowledge. com, Nmax = 583 is substituted into the formula to calculate the result, i.e., $M \approx 18.08$, which is rounded to the nearest whole number, i.e., 18 pieces of research results. According to the data exported from CiteSpace, the keyword is I = 583, and substituting it into the formula, the result is $T \approx 18.08$, which rounds up to 18 research articles. Accordingly, it is concluded that in the field of sociology of education research in China, keywords appearing 18 times or more are defined as core keywords.

Clicking Network Summary Table can get the detailed parameters of the keywords and after sorting can get the co-occurrence frequency of the keywords; among them, there are 15 keywords with frequencies greater than or equal to 18, and the information on keyword frequency descending order is listed in **Table 3**.

Table 3. Keyword ordering

No.	Frequency	Centrality	Year	Keyword
1	203	0.81	1999	Mathematics education
2	28	0.07	2000	Mathematical Culture
3	23	0.05	2017	Core competencies
4	22	0.07	2003	Mathematics teaching
5	22	0.03	2016	Mathematical Core Literacy
6	21	0.06	1998	Mathematics courses
7	17	0.04	1998	mathematics
8	16	0.04	2001	compulsory education
9	16	0.03	2014	Mathematical literacy
10	16	0.02	2004	History of Mathematics
11	14	0.1	2001	Primary school mathematics
12	13	0.04	1998	United States
13	12	0.02	2000	Curriculum reform
14	12	0.02	2006	criterion for curriculum
15	12	0.01	2008	enlightenment

3.3.1. Analysis of core keywords

Combining the keyword co-occurrence chart and the statistical table of China's mathematics education research, the core keywords are "mathematical culture" (28), mathematics carries ideas and culture, and is an important part of human civilization. Luogeng Hua said, "The universe is big, the particles are small, the rockets are fast, the chemical industry is clever, the earth is changing, the biology is mysterious, the daily life is complicated, and mathematics is everywhere" [6]. The fact that researchers can focus on mathematical culture shows that mathematics education researchers have a broad vision. Quality education is education based on the needs of human development and social development, with respect for students' subjective position and initiative spirit, and focusing on the formation of sound human personality as the fundamental characteristics[7]. The keywords "Core Literacy" (23), "Mathematical Literacy" (16), and "Mathematical Core Literacy" (22) can reflect the scholars' focus on the essence of education, which is anchored in every individual's development. Mathematics curricula comprise a variety of elements such as curriculum structure, curriculum objectives, curriculum content, learning styles, teaching materials, and so on. The presentation of the keywords "mathematics teaching" (22), "mathematics curriculum" (21), "curriculum reform," and "curriculum standard" (12) suggests that scholars were able to closely integrate mathematics education with the concrete implementation of the mathematics curriculum in order to promote mathematics curriculum reform.

The prominence of "the United States" (13) suggests that scholars of mathematics education are able to focus on the international community and conduct comparative studies based on the local context in order to build on their strengths and avoid their weaknesses. For example, some scholars explored MSA, a mathematics teaching and assessment model jointly proposed by Professor Shuhua An of the College of Education at California State University, Long Beach and Professor Zhonghe Wu of the College of Education at National University. The MSA model is both an effective and operational way of teaching mathematics and a mathematical assessment model [8]. The use of MSA mathematics teaching not only promotes learners' mathematical competence but also facilitates the cultivation of learners' mathematical affective attitudes and values. At the same time, MSA helps

to improve the teaching knowledge and skills of mathematics teachers [9].

3.3.2. Cluster analysis

In the course of this paper, a cluster analysis of the keywords of 1,000 texts related to Mathematics Education was carried out with the aim of exploring and analyzing the main content classifications in this subject area (**Figure 8**). The clustering map is analyzed and evaluated by means of a network signature analysis, with a Mean Silhouette *S* of 0.9244 (> 0.5) and a Modularity *Q* of 0.6963 (> 0.3), which indicates that the structure of the clusters is significant and that the clustering status is reasonable. There are nine color blocks in the figure, which represent nine clusters, and the label of each cluster is a keyword in the co-occurrence network, and the serial numbers of the clusters are #0~#9, the bigger the number is, the fewer keywords are included in the clusters. The more connecting lines between nodes within each cluster reflect a higher degree of co-occurrence between keywords in the domain. Based on **Figure 8**, we can see that China's mathematics education research can be summarized under the following themes: "#8 Primary Mathematics" focusing on the primary school section, "#7 China" focusing on comparative research, "#1 Mathematics," "#2 Core Literacy" focusing on core literacy, "#6 Quality Education," "#5 Mathematical Literacy," and "#4 Mathematical Core Literacy." Among them, "#8 Primary Mathematics" and "#4 Mathematical Core Literacy" show a cross, indicating that scholars are more concerned about the enhancement of the core literacy of primary school mathematics students. This is consistent with the hierarchical relationship of the curriculum objectives of China's New Mathematics Standard, which is "three skills leading four basic skills and four abilities."

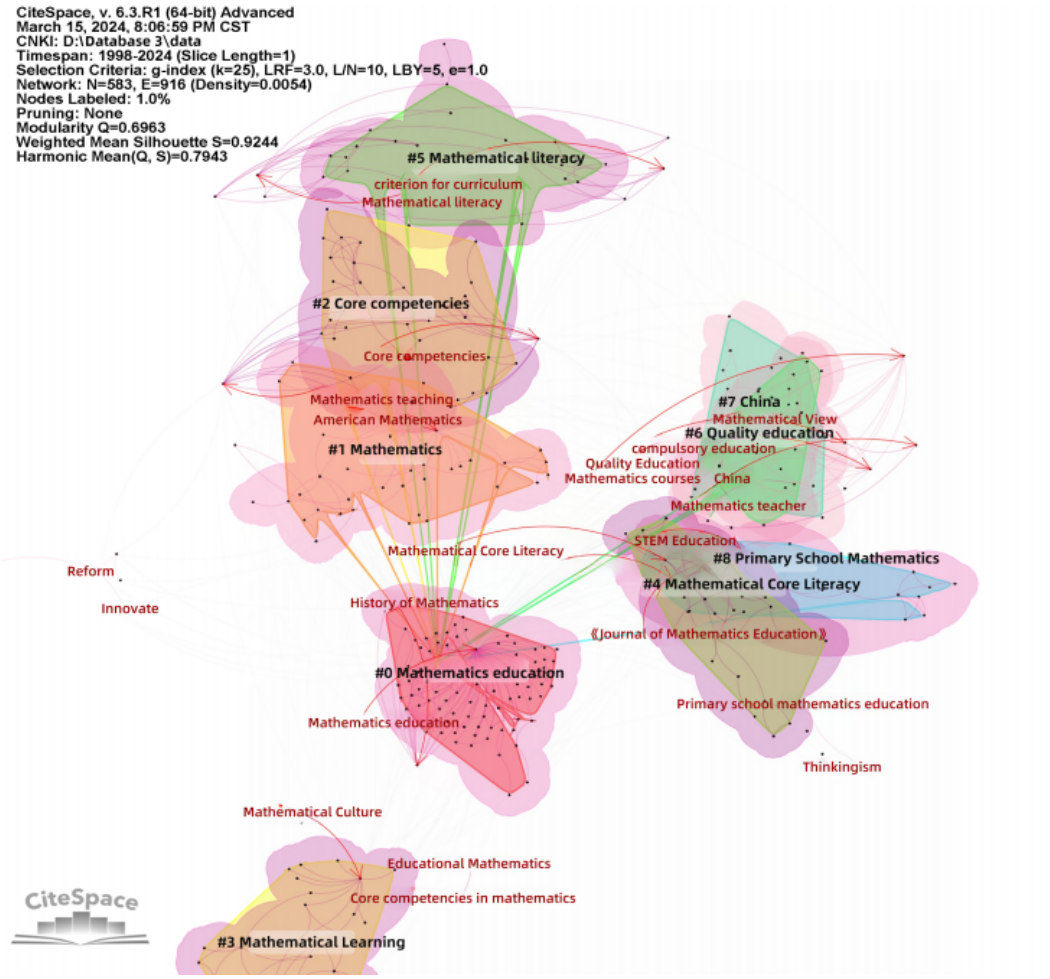

Figure 8. Keyword clustering

3.3.3. Analysis of time zone map of keywords

In order to further study the change of the main keywords, a left-to-right, bottom-up map of the evolution of research in mathematics education is presented (**Figure 9**).

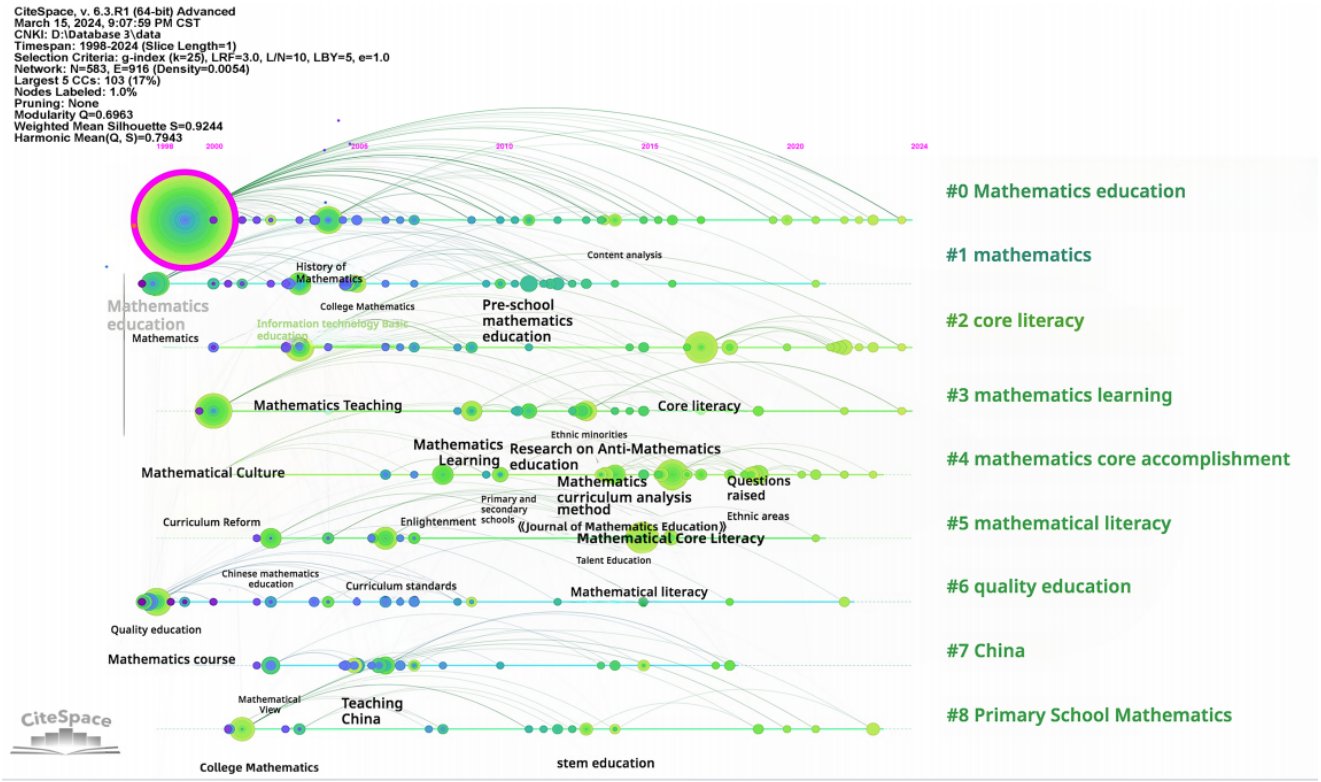

Figure 9. Time zone diagram

In 1998, the keyword "quality education" came to the fore, which coincided with the introduction of "quality education." Quality education is an original Chinese educational idea put forward in the 1980s in response to the problem of teaching to the test in basic education, with the main idea being to promote the all-round development of students. Its original ideological source is to improve the quality of the nation and the quality of workers [10]. The implementation of quality education is to promote the free and comprehensive development of human beings [11]. In the 21st century, the keyword "curriculum standard" is highlighted, which is consistent with the promulgation of the Full-time Compulsory Education Mathematics Curriculum Standard (Experimental Draft), but there is an obvious lag, the document was promulgated in 2001, and the relevant research was conducted only after 2005. The keyword "core literacy" was repeatedly presented after 2015, which is consistent with the time of the introduction of "core literacy," indicating that mathematics education research closely follows the current hotspots and policies. In 2016, the general framework of China's core literacy for students' development released by the research group led by Chongde Lin proposed that "The core literacy of student development is the necessary character and key abilities that students gradually develop in the process of receiving education at the corresponding academic level to meet the needs of lifelong personal development and social development" [12]. The presentation of the keyword "core literacy in mathematics" was before 2017, The Curriculum Standard for General Senior Secondary Mathematics (2017 Edition) [hereinafter referred to as the Senior Secondary School Curriculum Standard (2017 Edition)] explicitly puts forward the "core literacy in mathematics." The Ministry of Education [13] suggested that mathematics education research serves as a guide for policy documents. The prominence of the keyword "STEM education" is also a highlight,

STEM education originated in the United States and is a national development strategy proposed by the United States in order to meet the challenges of future social development. Zheng [14] showed that scholars related to mathematics education research are able to look at the world, base themselves on the local area, and fully draw on the advanced civilization achievements of other countries.

4. Conclusion

This paper conducts quantitative analysis based on research needs, displays the analysis results through data distribution and graphic form, and specifically summarizes the following research conclusions:

Firstly, China's mathematics education research focuses on mathematics teaching research and mathematics core literacy research, but involves less horizontal comparison between similar disciplines and cross-study. For example, the commonality of mathematics, physics, chemistry, and science and technology comparative research. The reasons are that there are fewer specialized scholars in the fields of mathematics, physics, and chemistry studying at the same time, and there is less cooperation and communication between scholars in different disciplines.

Secondly, China's mathematics education research should enhance cultural critical awareness to assess the international research frontiers. Understanding the progress of international research in mathematics education can help expand researchers' horizons and bring inspiring thoughts. From the keyword "the United States," we can see that the international vision of mathematics research in China is relatively limited, and we need to look at the whole world and make comprehensive comparative analyses. However, the purpose of mathematics education research is to improve teaching practice and serve the development of education, so research must be rooted in the soil of local culture. When introducing international mathematics education theories or practices into China, researchers need a deep sense of cultural criticism and creative research work. The borrowing of foreign educational theories must be based on cultural comparisons, breaking through the "discontinuous fragmented schema" to achieve a holistic cultural construction [15]. Through the comparison of cultures in different regions, we should think about the issues of "whether it is necessary," "whether it is suitable," and "how to turn it into local theories," and carry out exploratory theoretical research and validation of practical research.

Disclosure statement

The authors declare no conflict of interest.

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