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Professional paper

BIBLIOMETRIC ANALYSIS OF DIGITAL TOOLS IN MATHEMATICS EDUCATION: TRENDS, COUNTRIES, AND EMERGING KEYWORDS

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Abstract

This work undertakes a bibliometric study and analysis of the scientific literature dealing with digital tools in teaching mathematics from 2000 to 2025, sourced from IEEE Xplore. Its goal is to shed light on thematic trends, geographical research impact, and common keywords, titles, and co-authors in this very rapidly evolving world. The data set contains 1,152 scientific contributions, mostly conference papers (80.38%), reflecting the dynamic and ever-changing nature of the field. Keyword analysis unveiled five thematic clusters, indicating the integration of STEM, AI, and cybersecurity in education methodologies. The United States remains at the top in terms of citation and h-index, followed by China, Israel, India, and Canada. Within the Balkans, Turkey enjoys scientific supremacy, while North Macedonia seems starved of recognition, with a single publication to its account, and none cited. According to the results, the research interest is shifting away from work on traditional educational constructs to those on artificial intelligence in education and science.

Keywords: Bibliometric analysis, digital tools, mathematics education, artificial intelligence, STEM.

1. Introduction

The past decades have witnessed the integration of digital technology in the teaching of mathematics, greatly altering the method of knowledge delivery, understanding, and assessment. With emerging technologies like artificial intelligence (AI), machine learning, and STEM pedagogies revolutionizing the way education is done (Luma-Osmani et al., 2017), it is important to know the trends and implications of international research in this regard. Several researchers have noted positive effects of the use of digital technology during lessons (Drijvers, 2016). The increasing proliferation of such tools has allowed educators to shift from didactic chalk-and-talk approaches to more student-directed, inquiry-based teaching. Instead of merely solving a formula on the board, for example, teachers can use computer programs to demonstrate how graphs or equations alter in real time as variables are adjusted. This permits students to experiment, form hypotheses, and observe connections between mathematical ideas and real-world applications (Luma-Osmani et al, 2020). Furthermore, digital means can be attuned to different learning styles and abilities, bridging knowledge gaps and facilitating inclusive education.

2. Research Methodology

The research methodology of our study includes three main phases: starting with the collection of electronic documents based on our queries and requirements, followed by data processing and visualization, and finally concluding with future work and the study's limitations, as displayed in the figure below.

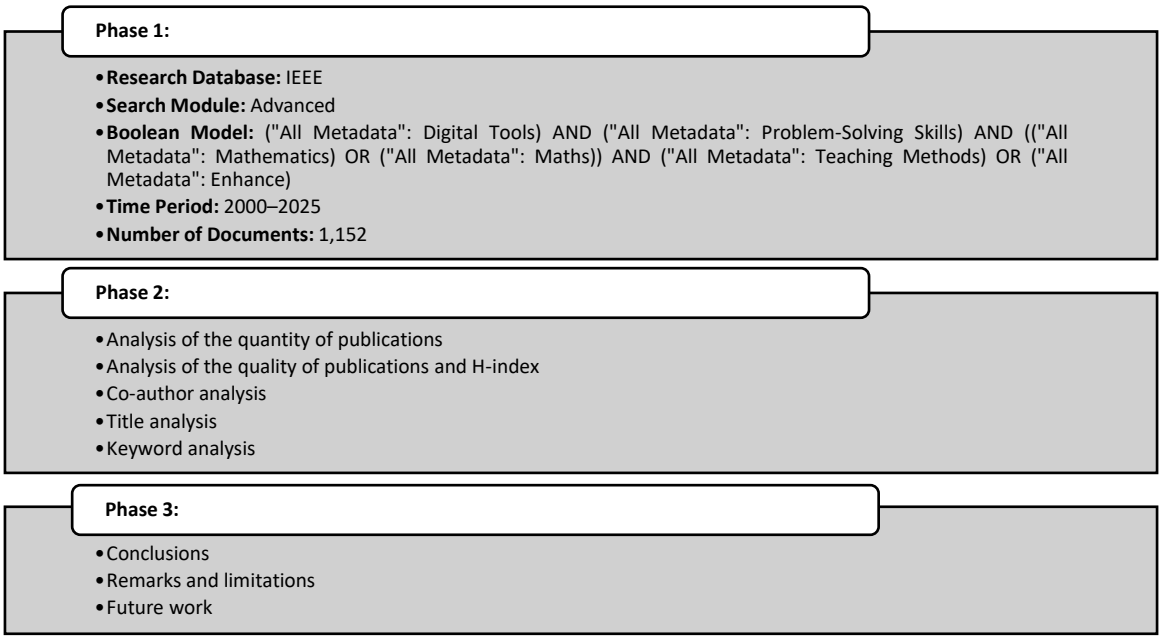

Figure 1. Research Phases

Based on the data retrieved from the internet for the period 2000–2025 and according to the specified criteria that we put, a total of 1,152 research papers were generated in the digital IEEE library. Among these, the majority is conference papers with 926 entries, accounting for 80.38%, followed by journals with a total of 194 (16.85%). In third place are magazines with 16 publications, or 1.39%. Books and early access articles have equal representation, with 8 documents each, or 0.69%.

Table 1. Type of Documents

Doc. Type	Frequency	Percentage
Conferences	926	80.38
Journals	194	16.85
Magazines	16	1.39
Books	8	0.69
Early Access Articles	8	0.69
Total	1152	100%

The chart below in Figure 2 illustrates the 25 years of publications in the field under study. We can observe that from the year 2000 to 2020, there was a relatively modest number of publications in this area. However, after 2020, there was a significant increase in publications, indicating that more and more researchers have started engaging with this topic. In 2024, there is a notable spike, reflecting a growing interest in the use of digital tools in mathematics education and related fields.

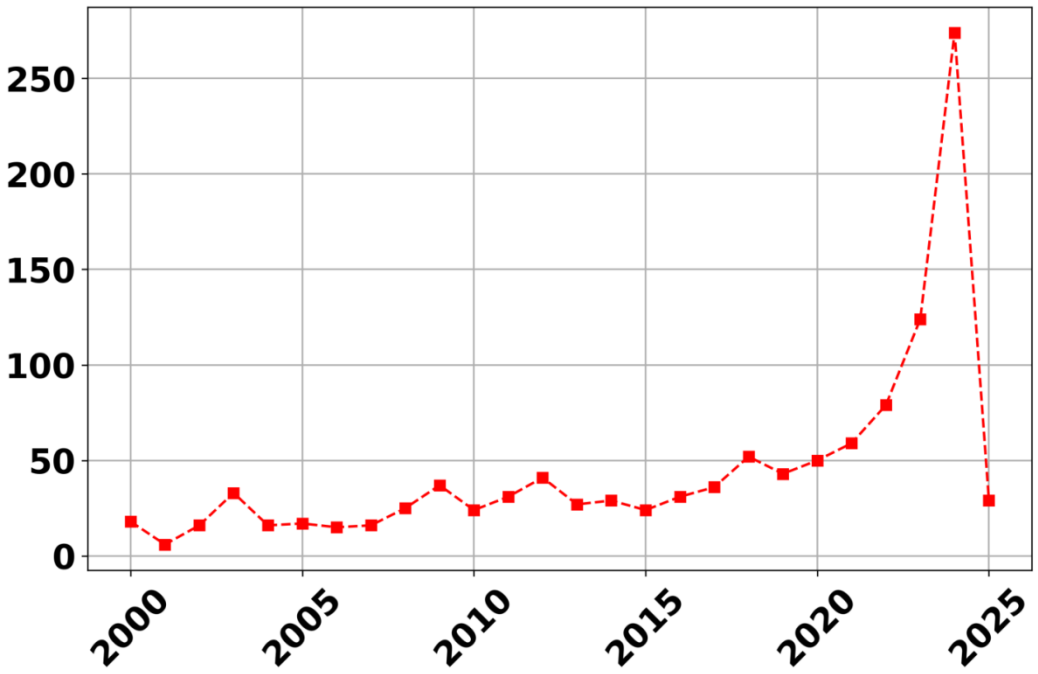

Figure 2. Temporal Distribution of Publications

Such an increase may result from rapid technological advancements, the rising demand for personalized learning, and wide post-pandemic adoption of digital platforms. The topic is both current and rapidly evolving.

When analyzing the number of publications focused on the use of various digital tools in mathematics teaching, we notice that the United States leads in the number of studies, closely followed by China. India ranks third, while the United Kingdom, Taiwan, Canada, and Germany show similar levels of research activity. Following them are countries like Malaysia, Italy, Russia, and others. All of this is illustrated in Figure 3 below.

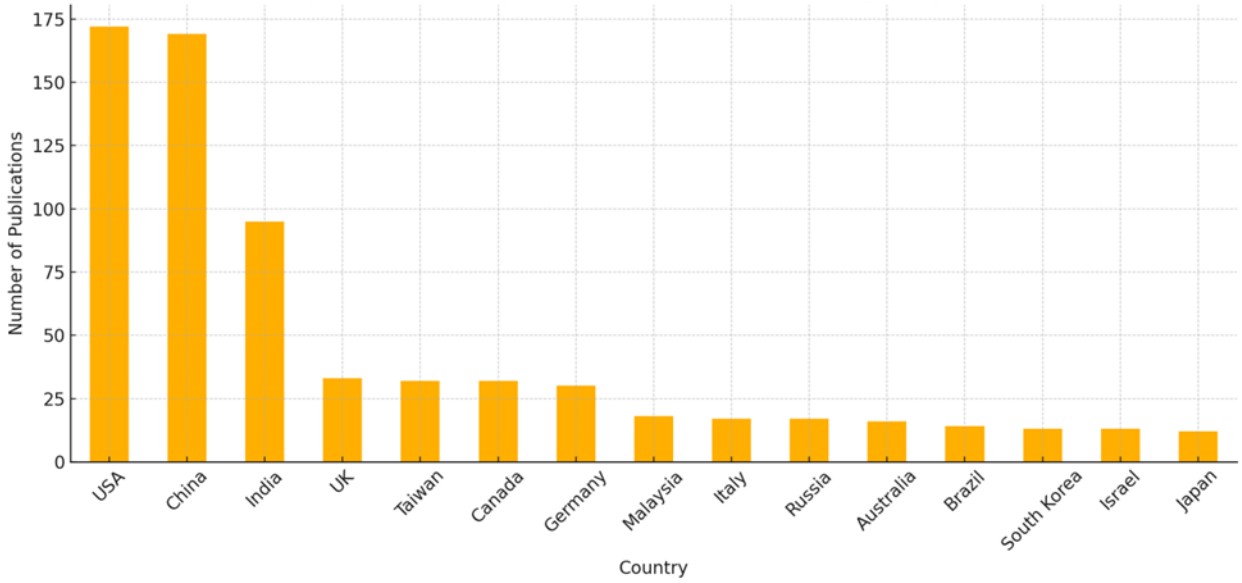

Figure 3. Number of Published Papers

Next, we analyze the top 15 countries with the highest number of citations, which serves as an indicator of publication quality, along with the H-index. To clarify, the H-index is a metric that measures scientific impact, indicating how productive and how frequently cited a researcher or

a country is. It is determined by the number of publications and the number of citations per publication In general, the H-index reflects a combination of quantity and quality. For example, an H-index of 7 means a researcher has 7 papers that have each been cited at least 7 times (Engqvist, L. and G. Frommen, J., 2008).
The chart illustrated below in Figure 4 represents the scientific contribution and impact of different countries in literature related to digital tools in mathematics, based on data from the IEEE electronic library.
It is important to note that the total number of citations in the dataset is 6,396. The data show that the USA leads with over 5,000 citations and a very high H-index, indicating both volume and quality. China follows with over 4,000 citations, closely trailing the U.S. and Israel, although having fewer publications, shows a strong H-index, indicating consistent impact. India and Canada are also among the top contributors, though with a more moderate citation distribution.

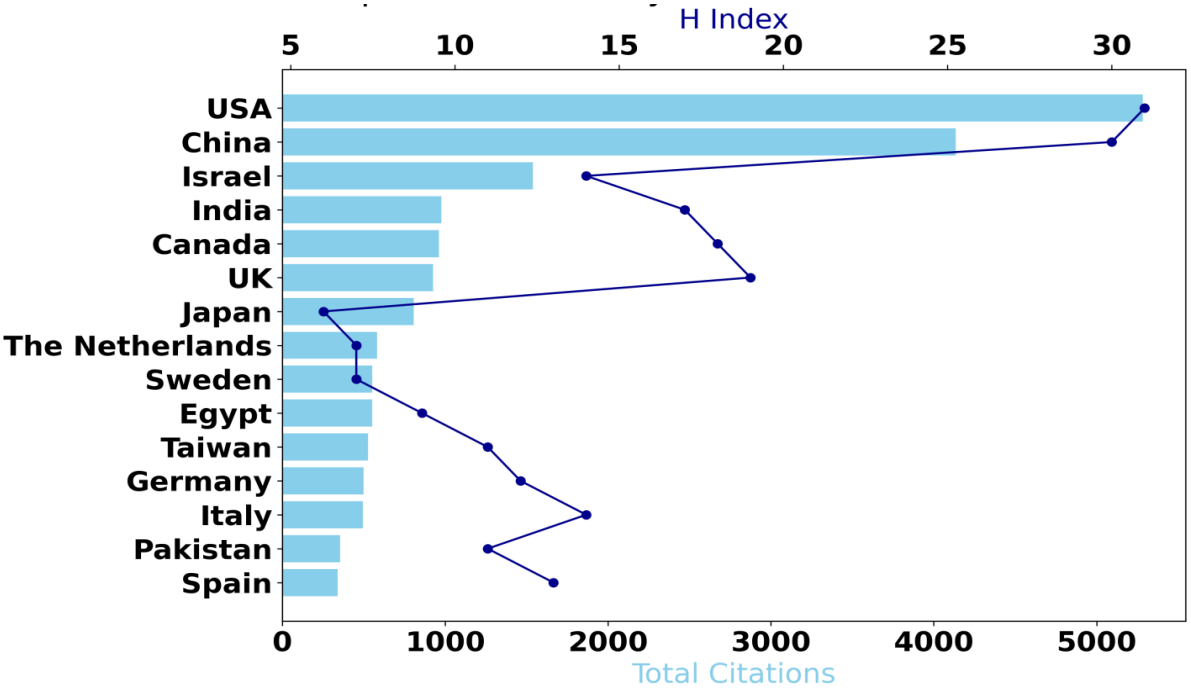

Figure 4. Citations and H-Index Worldwide

Bibliometric analysis reflects Turkey's claim as the number one country in the Balkan region with reference to citations and H-index, indicating that Turkey has a strong and consistent presence in the scientific literature on digital tools in mathematics education. Greece and Croatia follow somewhat similarly with the same H-index of 6, while Bulgaria and Romania come less so with lesser citation counts and H-index. North Macedonia is present only through one publication, which, as of now, has no citations recorded in the dataset (see figure 5).
This clearly exposes that while some of the Balkan countries are already working in this field, there is plenty of chance for wider regional involvement in making impactful scientific research.

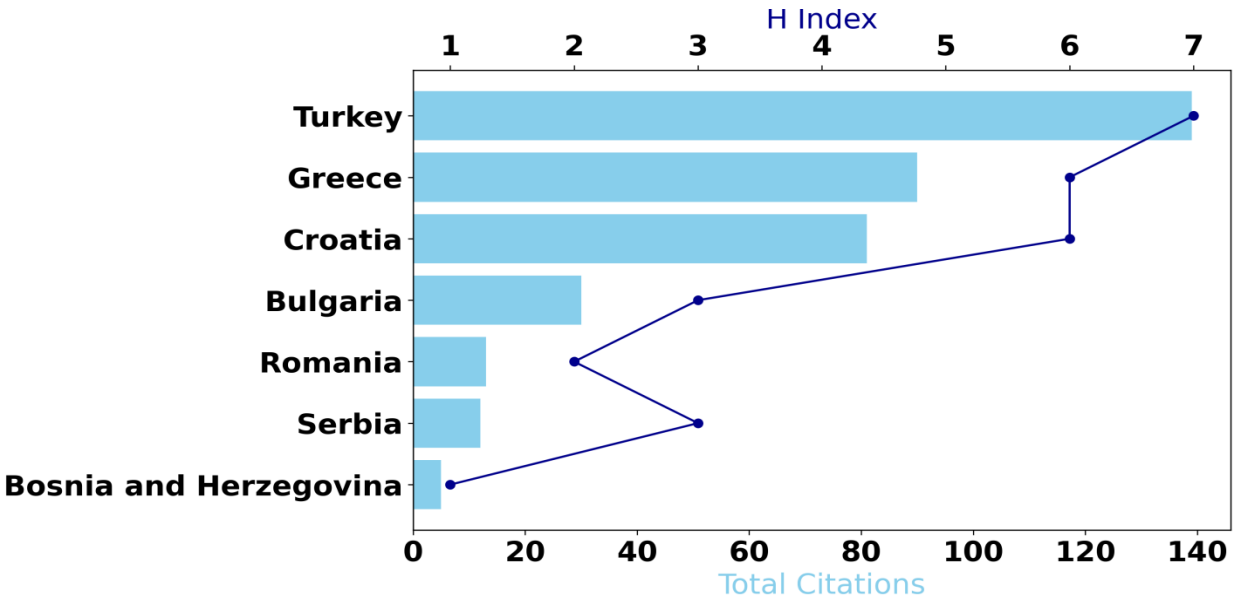

Figure 5. Citations and H-Index in the Balkans

2.1 Co-Author Analysis: Our dataset contains 1,152 publications authored by a total of 3,692 researchers. The co-author analysis focuses on identifying the scholars who have collaborated most frequently in the field under study. The analysis reveals: 34 researchers co-authored 5 publications, 52 researchers collaborated on 4 publications, and 123 researchers were involved in 3 publications. The minimum threshold for this analysis was set to researchers who have co-authored at least 2 papers, resulting in a network of 370 authors. Authors sharing the same color cluster in the visualization represent research groups or teams that have consistently collaborated. Notably, the most active and prominent contributors to this field include G. Srivastava, H. Wang, J. Zhang, and Z.C. Eldar. This co-authorship network is illustrated in Figure 6.

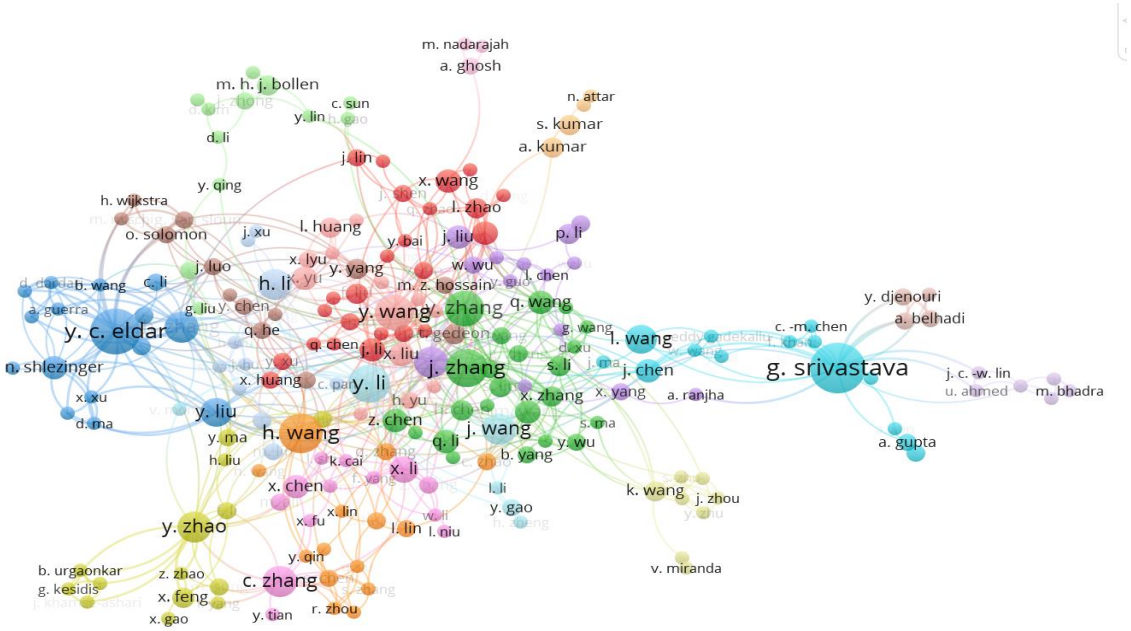

Figure 6. Bibliometric Analysis of Co-Authors

2.2 Title Analysis: The analysis of the title network identifies several key clusters (distinguished by color), which represent the main research themes and areas of interest in the literature.
The blue category includes themes like training, education, math, and STEM education. STEM stands for Science, Technology, Engineering, and Mathematics. Educational software tools and technologies are also included in this category, indicating an emphasis on good instruction, mathematical problem-solving, and technology applied to instruction.
The green group has expertise in computer modeling, mathematical models, artificial intelligence, deep learning, and applications for biomedical imaging. This cluster is defined by intense focus on applied mathematics, advanced algorithms, and using these types of methods in real systems.
The red category is associated with cryptography, security, algebra, and system strength. This keyword category highlights the importance of theoretical mathematical foundations and their application in computer security and sophisticated data protection schemes.
The purple cluster addresses problems related to computer games, gamification, serious games, and interactive methods. This cluster is concerned with the potential of virtual games and interactive technologies in optimizing learning process productivity and learner engagement.
The orange cluster includes educational institutions, engineering education, educational programs, and training professionals. These topics focus on the institutional and professional aspects of engineering education, educational program design, and how they operate to advance future professionals.
Overall, this network demonstrates the diversity of research topics, covering educational technology, applied mathematics, computer security, interactive technology, and professional education in engineering.

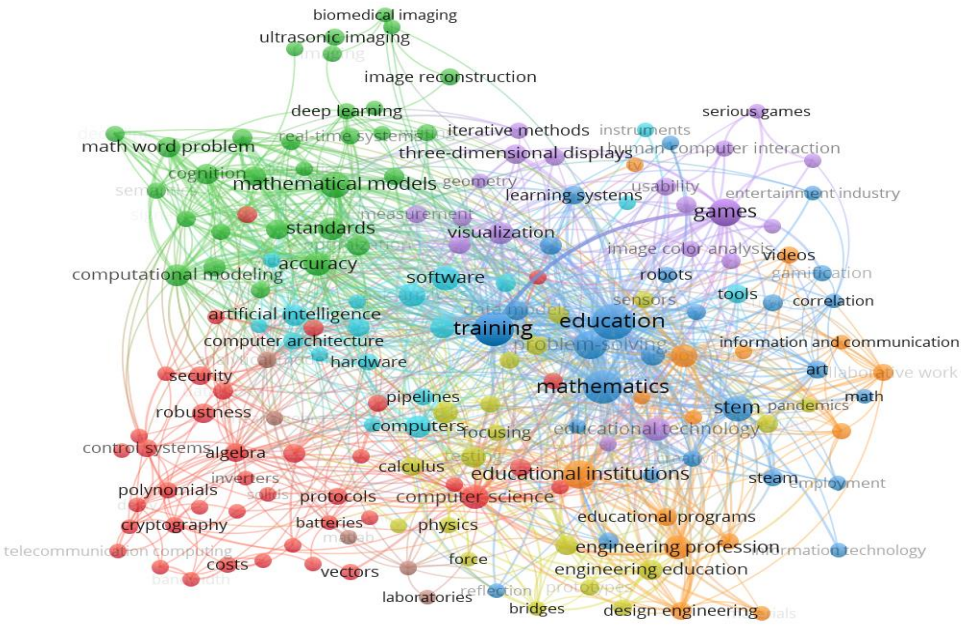

Figure 7. Bibliometric Analysis of Titles

If we conduct a temporal analysis from the year 2000 to the present, the titles of publications related to the use of digital tools in mathematics teaching have evolved significantly as a research field:

- Initially, the focus was dominated by themes related to educational institutions and algebra.

- Around 2010, the scope expanded to include mathematics, education, and computer games.
- After 2020, the primary attention shifted toward artificial intelligence, mathematical models, software, and data visualization.

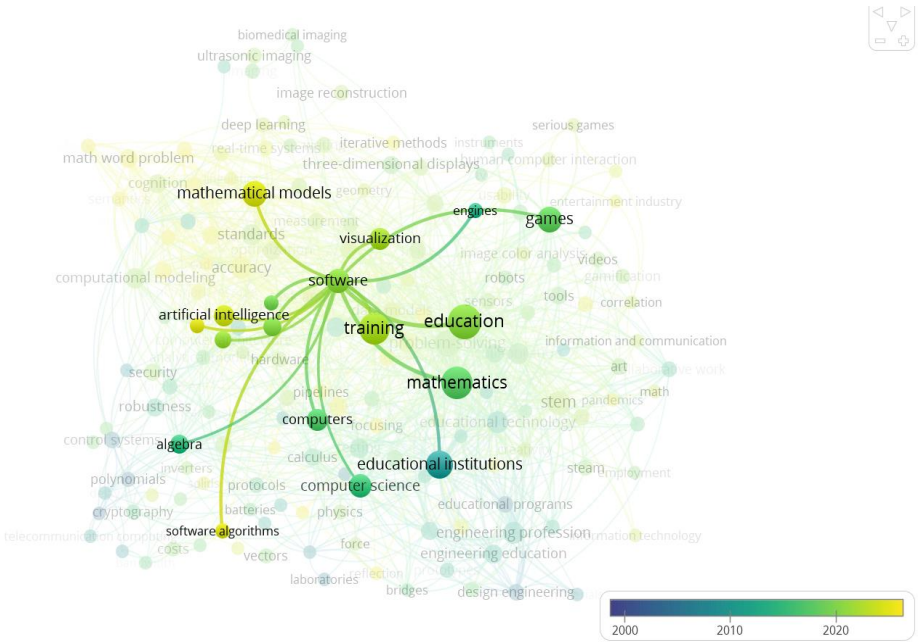

Figure 8. Time Span Bibliometric Analysis of Titles

2.3 Keyword Analysis: In our dataset, the total number of unique keywords (non-repetitive) is 3,518, while the total number of all keywords (including repetitions) is 4,485. For our analysis, we focus exclusively on the unique keywords. During data analysis, we found the following frequency distribution among the 3,518 unique keywords:

- 15 keywords appear 10 times, 19 keywords appear 9 times, 24 keywords appear 8 times, 27 keywords appear 7 times, 38 keywords appear 6 times, 55 keywords appear 5 times, 89 keywords appear 4 times.

We set a minimum threshold of 3 appearances for keywords to be included in the analysis. Based on this criterion, the total number of keywords analyzed was 158.

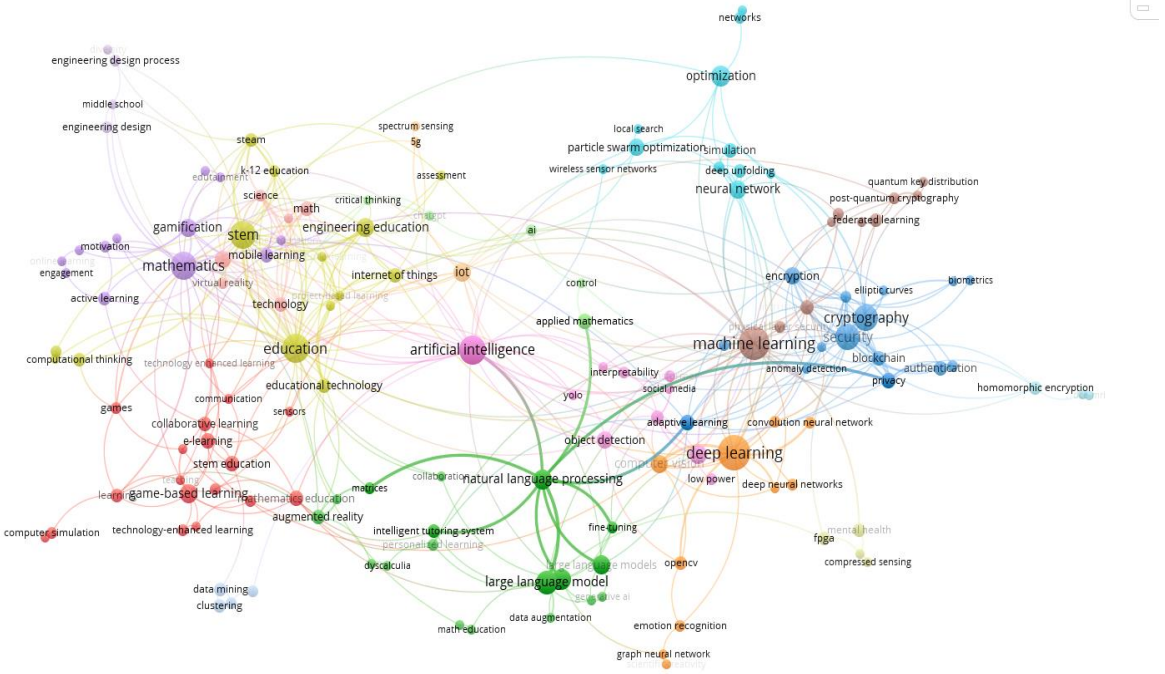

Figure 9. Bibliometric Analysis of Keywords

The same result is obtained even when the data is presented in the so-called density map, as shown in Figure 10, where the most frequently used keywords are highlighted.

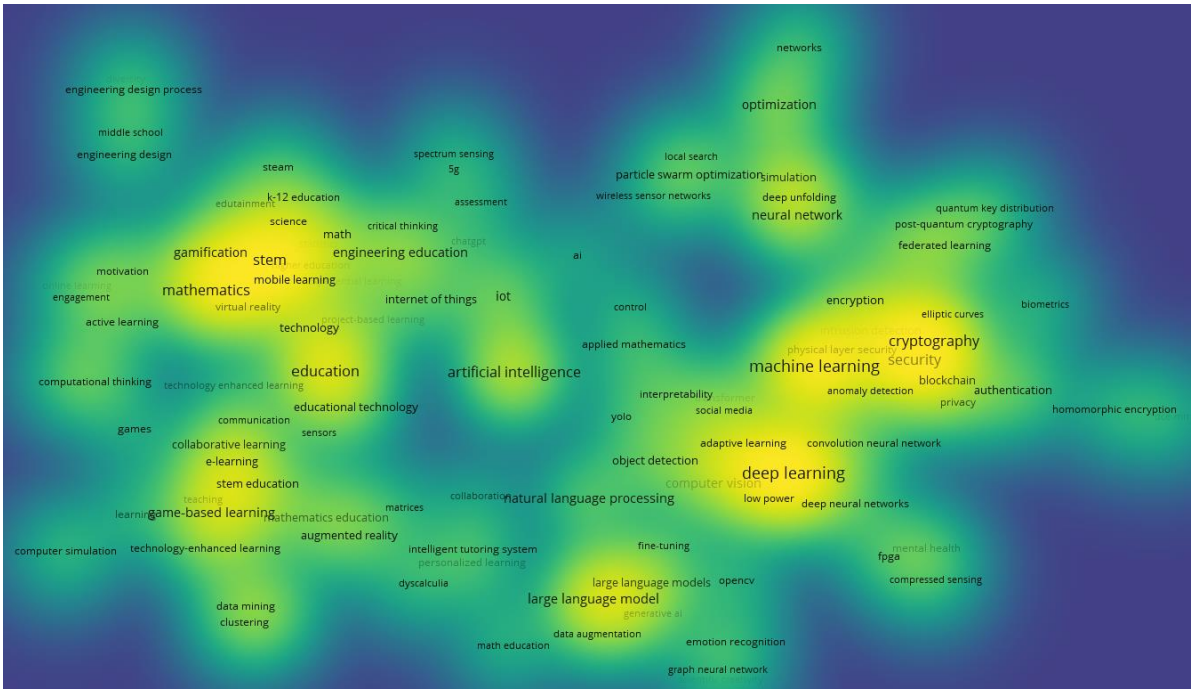

Figure 10. Keywords Density Map

If we pause and examine the **top 10 most frequently used keywords** in the literature within the IEEE electronic library, we see that the term **"Deep Learning"** is leading, as shown in Table 2.

Table 2. Top 10 Keywords

#	Keyword	Frequency
1	deep learning	33
2	machine learning	30
3	education	23
4	stem	22
5	mathematics	21
6	artificial intelligence	20
7	cryptography	19
8	security	19
9	large language model	13
10	optimization	12

The following chart represents the trend in the application of five keywords over two decades, comparing the manner in which some of the most highly ranked keywords applied in scientific journals have developed on a yearly basis. From this analysis, the five most common keywords were ascertained, and the quantity of times for each of these, categorized by publication year, has been plotted. We observe that Machine Learning and Deep Learning have experienced a dramatic and steep increase after 2020, peaking in 2024. This is an indication of a definitive shift towards research interest in artificial intelligence. STEM, Education, and Mathematics have been present since the beginning of the dataset, indicating a steady growth, but nowhere close to the level of the recent technologies. Overall, after 2020, all the keywords experienced a firm growth, especially on issues that include AI and emerging technology in education.

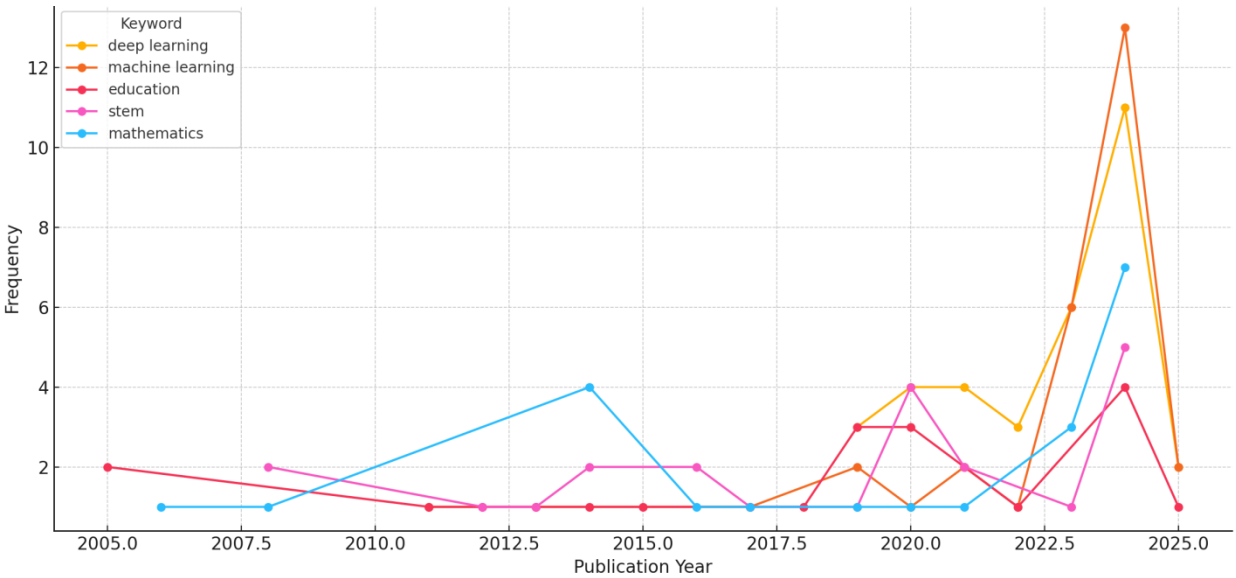

Figure 11. Keyword Trends

3. Conclusions

This study presents an extensive bibliometric survey of scientific articles on the use of computer tools in math education between 2000 and 2025 based on IEEE Xplore content. The goal is to uncover thematic trends, geographic research impact, and the most frequent keywords, titles, and co-authors in this fast-paced scholarly field. 1,152 scholarly articles comprising mainly conference papers (80.38%) corroborate the active and ongoing evolution of the field. Five clusters emerged with keyword analysis placing focus on STEM integration, AI, and

cybersecurity in pedagogical practice. The United States has the highest number of citations and H-index, followed by China, Israel, India, and Canada. Turkey is the most dominant scientific influence in the Balkans and has the least presence of North Macedonia, with a single publication but no citations. Results indicate a change in research interest from traditional issues of education to the use of artificial intelligence in science and education. Data visualization is a helpful reference for policymakers, researchers, and institutions to identify the most active and productive nations in fostering innovation in mathematics learning through digital technology. The U.S. is at the top in the number of total citations, which reflects high research activity and a broad global reach in this field. China, Israel, and the UK also show high concentrations of citations, which is a measure of high investment in educational technology and higher-order digital education. The H-index tells us not just about the quantity but also about the quality of each country's publications consistently, showing us that some countries have fewer citations in total but equal H-index ratings, which indicates that these countries have consistent and balanced scientific contributions. At the international level, contributions come from countries on every continent, with the strongest dominance being North America and East Asia. It is also noticeable that mathematical areas that make use of digital tools are developing robustly and evenly all around the globe.

3.1 Limitations: This study is helpful in knowing how digital tools are applied in mathematical instruction, but has limitations since it was based on IEEE Xplore data alone and primarily on conference proceedings, excluding other major databases like Scopus and Web of Science. This may limit the full representation of the field and the intensity of scientific investigation.

3.2 Future Work: Follow-up research must continue by capitalizing on additional databases and venturing into qualitative exams of publication text. Future studies will continue with the development of personalized AI tutors, using virtual reality to support learning abstract ideas, and measuring the real-world impact of technology on student performance. It will be important as well to bridge digital divides and improve teacher training for effective technology use and cybersecurity in schools.

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