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Research Trends in Scopus Database on Technological Innovation in the Process of Mathematics Learning: A Bibliometric Analysis

Suripah[1], Heri Retnawati[2], Zetriuslita[1], Zafrullah[3], Riyan Hidayat[4]*

[1]Department of Mathematics Education, Universitas Islam Riau, Pekanbaru, Indonesia,
e-mail: rifah@edu.uir.ac.id, zetriuslita@edu.uir.ac.id
[2]Department of Mathematics Education, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia,
e-mail: heri_retnawati@uny.ac.id
[3]Educational Research and Evaluation, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia,
e-mail: zafrullah.2022@student.uny.ac.id
[4]Department of Mathematics Education, Universiti Putra Malaysia, Malaysia, e-mail: riyan@upm.edu.my

Abstract: The purpose of this analysis is to look at publication trends in research on technological innovation in the process of mathematics learning analyzed by bibliometric analysis. Using predetermined keywords, the authors analyzed 262 documents that had been selected by the PRISMA method, with the next step being bibliometric analysis with the R Program and VOSviewer. From the analysis, research on technological innovation in mathematics learning started in 1987 and showed significant growth until 2024, with a clear surge in publications since 2010 and a peak in 2023. The United States and Australia lead the way in the number of publications and citations, demonstrating their great influence in this field. Universiti Putra Malaysia, along with leading universities in Australia and South Africa, show dominance in publications related to this topic. Journals in the Q1 category play a major role in advancing knowledge about technology in mathematics education, In the keyword grouping, new trends are emerging such as the use of technologies like "Artificial Intelligence" and "Blended Learning" which are becoming new directions in technological innovation in the process of mathematics learning.

Keywords: *technology, mathematics learning, bibliometric.*

Introduction

The development of education after war has undergone a significant transformation, with many countries seeking to rebuild their education systems to support social and economic recovery (Ma et al., 2022). Education serves not only as a tool to disseminate knowledge, but also as a means to shape character and prepare young people for future challenges (Behnamnia et al., 2020; González-Pérez and Ramírez-Montoya, 2022; Izzulhaq et al., 2024). The existence of inclusive and quality education is becoming increasingly important in a global context, where access to education can help reduce social inequalities and improve people's well-being. By utilizing technology and innovative teaching methods, education can reach more students, including those in remote areas (Munoz-Najar et al., 2021). Thus, the importance of schools as institutions that provide quality education cannot be ignored, as they serve as the main foundation in creating a smart and competitive society.

School is a vital place for children's intellectual and social development, where they learn various skills necessary for the future (Akour and Alenezi, 2022; Alam and Mohanty, 2023b). Schools not only provide formal education, but also shape character and values that are important in life (Dunne, 2021). Access to quality schools is essential to ensure that all children, regardless of their background, have equal

*Corresponding author: rifah@edu.uir.ac.id

opportunities to learn and grow (Alam and Mohanty, 2023a). However, there are still many challenges faced, such as limited facilities and resources that can affect students' learning experience. Therefore, attention to school conditions is crucial, as a good and supportive environment will have a direct effect on student motivation and success (Alemayehu and Chen, 2023). Thus, it is important to understand that optimal classroom conditions are instrumental in creating an effective learning atmosphere.

The classroom is a space that greatly influences children's academic and social development (Piipponen et al., 2024). In the classroom, they not only learn subject matter, but also develop social skills, such as communicating and cooperating with their peers (Kim et al., 2022; Saleem et al., 2024). These children's development is highly dependent on a supportive environment, so the condition of the classroom is a factor that cannot be ignored (Miller-Cotto et al., 2022). The school's attention to the comfort and completeness of classroom facilities is an important part of creating a conducive learning atmosphere (Feng et al., 2024). Classroom conditions should be designed in such a way as to inspire students to learn more vigorously and feel comfortable while being in it (Dai, 2021; Hsieh et al., 2020). With sufficient lighting, good ventilation and adequate equipment, the classroom will be an optimal place for student development. Therefore, attention to classroom conditions should not only focus on the physical space, but also how it supports the learning process and student motivation (Rusticus et al., 2023). This attention will go a long way in improving the quality of learning in schools.

Learning is a very important process in shaping students' intellectual, emotional, and social abilities (Gueldner et al., 2020). The important part of this education is how students can understand the material and apply it in everyday life (Chew and Cerbin, 2021). The effective learning process requires innovative and adaptive methods, so that students can more easily understand the various concepts taught (Morze et al., 2021). In creating a conducive learning atmosphere, teachers play a big role in choosing an approach that suits the needs of students. The supportive environment and active involvement of students will increase the effectiveness of the learning process (Raza et al., 2023; Sökmen, 2021). With the development of the times, many learning methods began to adapt to cover a variety of approaches, one of which is with technology that is increasingly integrated in the education system.

Technology is a very important tool in education, as it can enrich students' learning experience in many ways (Arulanand et al., 2020; Ruiz-Rojas et al., 2023; Sofi-Karim et al., 2023). It can help students to access information more quickly and efficiently, and allow them to learn in an interactive and practical way. Students can utilize technology to deepen their understanding through various educational apps, learning videos and other online resources (Sofi-Karim et al., 2023). In addition, technology can also provide simulations and visual tools that make it easier for students to understand complex concepts (Yıldırım et al., 2020). By optimally utilizing technology, students can learn in a way that is more engaging and suits their individual learning styles (Alam, 2023; Cabual, 2021). Therefore, the appropriate use of technology can be beneficial in improving the effectiveness of mathematics learning, by providing a more dynamic and comprehensible experience.

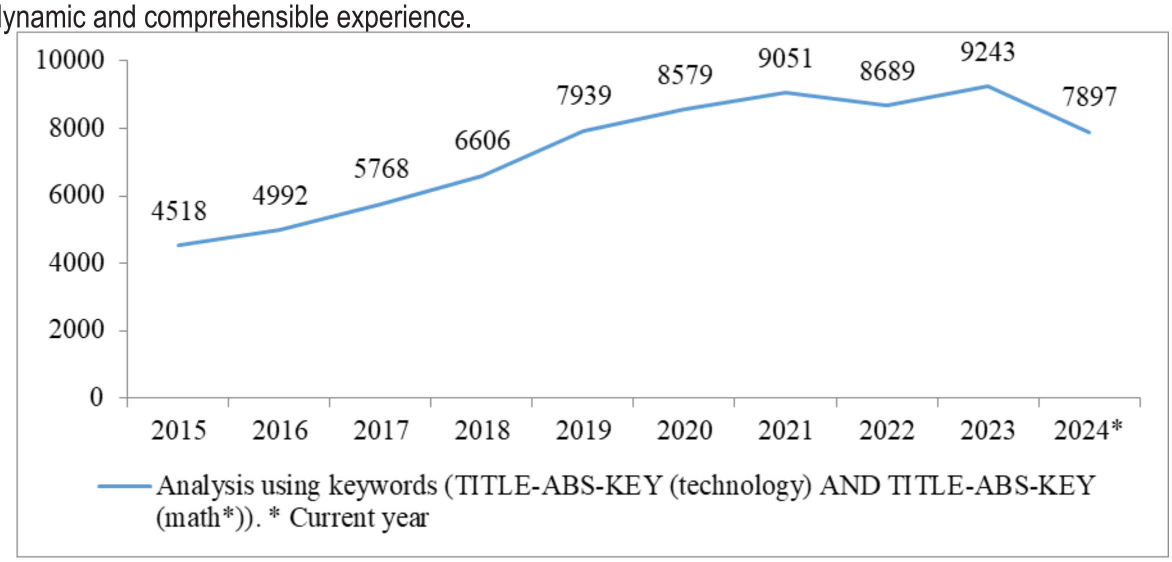

Figure 1. Trends Discussing Technology in Mathematics in the Scopus Database (Data retrieved on November 6, 2024)

Discussions on the use of technology in mathematics in general are increasingly discussed in various publications recorded in the Scopus database. As shown in Figure 1, the data shows a positive trend in the number of publications that generally address the topic of technology in mathematics from 2015 to 2021, with a consistent increase each year. This increase indicates the growing interest and attention of researchers in the application of technology in mathematics education, which continues to evolve with technological advances and the need for digital learning. However, in 2022, this trend experienced a significant decline, where the number of publications decreased from 9051 to 8689, which may reflect various challenges faced in technology research in mathematics education or a temporary decline in research interest. Nonetheless, the number of publications again showed an increase in 2023, suggesting that this topic remains relevant and attracts the attention of the academic community. Overall, these publication trends indicate a consistent and sustained interest in the topic of technology in mathematics, despite some fluctuations in the middle of the period studied, underscoring the importance of this topic in the modern educational domain.

Analysis of previous publications showed that the use of ICT in mathematics learning has increased significantly, especially in terms of ease of understanding and teaching effectiveness. The first study found an increasing trend of publications addressing ICT in mathematics since 2017, with a peak in 2019, and three main themes (Julianis, 2023). However, this study only focused on analyzing publication trends without looking at the contribution of inter-researcher collaboration or inter-institutional linkages. Meanwhile, the second study highlighted that while there are many publications addressing ICT in mathematics education, most of the current research tends to be published in sources with a low citation index and shows a lack of strong research collaboration, especially among international institutions (Trinh Thi Phuong et al., 2022). The shortcomings of these two studies suggest that while ICT in mathematics learning has been widely researched, there are still aspects that require updating, especially in optimizing international collaborations and exploring new themes that can enhance innovation in this area.

From the introduction and findings presented, the authors conclude that while the use of technology in mathematics learning has shown a positive trend in publications over the years, there are some challenges that need to be addressed, such as the sharp decline in the number of publications by 2022 and the low citation index of most recent publications. Although this topic continues to attract attention, the lack of inter-researcher and inter-institutional research collaboration, especially at the international level, is one of the shortcomings that need to be corrected. Therefore, there is a need for renewal in research on technology in mathematics learning, with a focus on optimizing international collaboration and exploring new themes that can drive innovation in mathematics education. So, the research questions can be described as follows:

RQ1. What is the main information, publication trends from year to year, collaborating and most productive countries, collaborating and most productive affiliates, most productive researchers, most productive sources, and documents with the highest citations on the topic on technological innovation in the Process in mathematics learning?

RQ2. How to group keywords and novelty keywords that can be recommended for conducting further research in the field on technological innovation in the Process in mathematics learning?

Materials and Methods

Research Design

This research is a bibliometric analysis on Technological Innovation in the Process mathematics learning. Bibliometrics is a method used to analyze scientific publications, including writing trends, citations, and collaboration between researchers in a particular field (Moral-muñoz et al., 2020; Tomaszewski, 2023). Through this approach, research developments can be mapped, emerging topics identified, as well as contributions from various countries and institutions to the topics discussed. In the context of technological innovation, bibliometrics can help to identify the latest applications of technology in mathematics learning and understand the extent to which this topic has received attention in the scientific literature. Thus, bibliometric analysis not only provides an overview of research trends, but also opens up opportunities for further innovation in the processes of the field of mathematics education.

Search Strategy

In searching for documents in the Scopus Database, the author uses the keywords "(TITLE (technology) AND TITLE (math*) AND TITLE (educat*) OR TITLE (learn*) AND NOT TITLE-ABS-KEY (stem) AND NOT TITLE-ABS- KEY (steam))". The author limits keywords by not involving the words STEM and STEAM. This is because the focus of this research is more emphasis on the use of technology in mathematics learning in general, without involving specific aspects related to science, technology, engineering and mathematics which are usually covered by the concept of STEM or STEAM. By avoiding these keywords, the author can ensure that the documents found are more relevant to the topic on technological innovation in the foundations and process in mathematics learning, without overlapping with broader topics regarding the overall discussion of STEM.

Data searches were carried out using the Scopus database, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology for document selection. This approach aims to provide a systematic and transparent document selection process, so that only truly relevant and high-quality articles are included in the analysis. By using PRISMA, the author can ensure that all steps for searching and selecting articles are carried out in a clear and structured manner (Page et al., 2021; Rethlefsen et al., 2021). So that the results of this research can be justified and provide an accurate picture of technological trends on process in mathematics learning.

Inclusion and Exclusion Criteria

At the Identification stage, the author entered keywords according to the provisions explained in the "Search Strategy" section, resulting in 751 initial documents. This stage aims to filter all documents that are potentially relevant to the topic of "Technological Innovation in the Process of Mathematics Learning", allowing for a more in-depth analysis. The selected keywords were designed to cover the main topic without including terms that could broaden the scope too much, such as "STEM" and "STEAM". The exclusion of "STEM" and "STEAM" terms was made to ensure that the obtained documents specifically focus on the application of technology in mathematics learning without expanding into broader educational contexts. In this way, the author hopes to gather articles that genuinely concentrate on the use of technology in the mathematics learning process.

At the Screening stage, researchers focused on the subject areas of "Social Sciences", "Computer Sciences", and "Mathematics", selected based on their relevance to technological innovation in mathematics education. These three fields encompass pedagogical aspects, technological advancements, and the application of mathematical concepts in digital environments. Documents classified as "Articles" were chosen because journal articles generally undergo a rigorous peer-review process, ensuring the validity and quality of the analyzed information. This selection successfully eliminated 428 unsuitable documents, leaving 323 for further analysis. At the Inclusion stage, the author conducted a manual review by examining the titles and abstracts to ensure each document was truly relevant to the research topic and did not include discussions that were too broad or unrelated. Inappropriate documents were eliminated, reducing the total by 61, leaving 262 documents ready for bibliometric analysis at this stage.

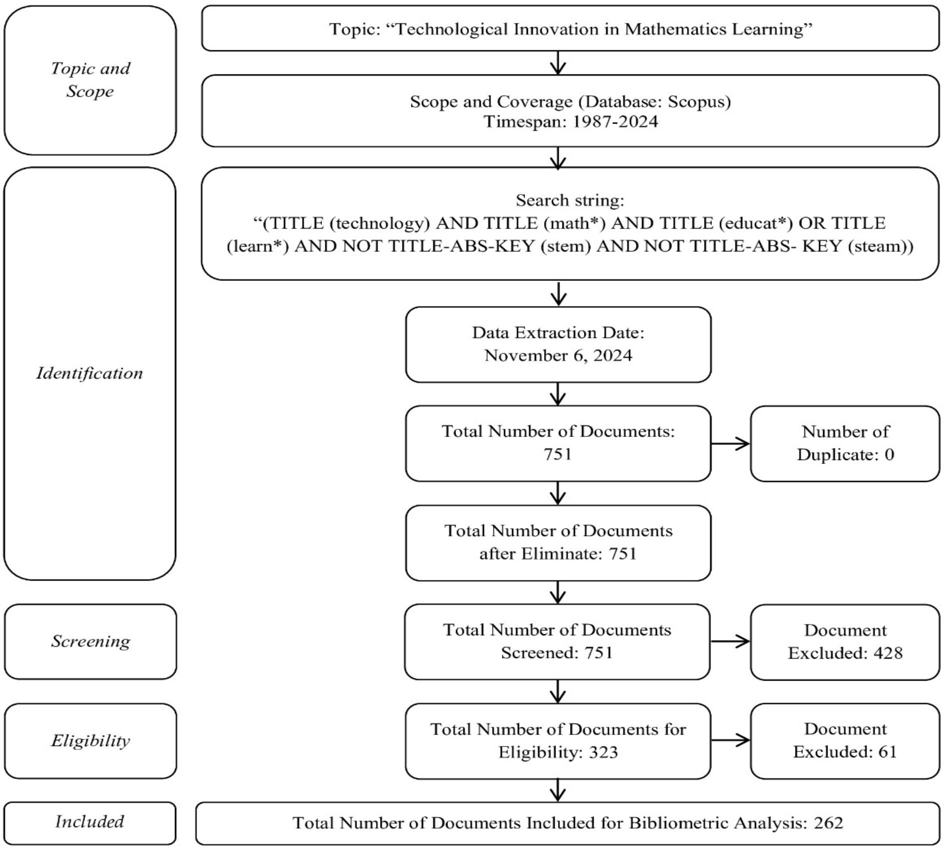

Figure 2. Document Selection Using the PRISMA Method. Flowchart by Page et al, (2021)

Data Analyze

After selecting documents and obtaining 262 final documents, the author continued with bibliometric analysis using VOSviewer software and the R program. With this method, the author was able to explore and compile a visual map of existing literature, thereby providing a comprehensive picture of research developments. This analysis begins by interpreting the first Research Question (RQ1), which includes main information, publication trends from year to year, as well as collaborating and most productive countries. Apart from that, the author also identified the most productive institutions and authors, as well as publication sources that produce the most documents in this field, to documents that have the highest number of citations. These steps aim to gain an in-depth understanding of the contribution and distribution of research related to technology in mathematics learning.

Next, the author interprets the second Research Question (RQ2) which focuses on group keywords and novelty keywords. This analysis is carried out to identify the main themes that emerge in the research, as well as innovations or new topics that may become trends in the future. By mapping these keywords, authors can understand how research focus changes and develops, as well as discover potential research areas that have not been widely explored. This keyword analysis also helped to uncover new aspects of technological innovation in the foundations and processes of mathematics learning, which could form the basis for further research or the development of more innovative methodologies in this area.

Results

The author answers RQ1 by presenting the results regarding main information, publication trends from year to year, as well as collaborating and most productive countries. Apart from that, the author also identified the most productive institutions and researchers, as well as publication sources that produce the most documents in this field, and documents that have the highest number of citations. These results were analyzed by using the R Program.

Main Information

In Figure 3, it can be seen that research on technological innovation in the process of mathematics learning began in 1987 and continues until 2024, with a total of 262 documents published. The average annual growth of publications in this field was 9.09%, indicating a consistent increase over time. A total of 153 reference sources were used as references, involving 644 authors. Of these authors, 53 of them are sole authors, while the level of international collaboration reached 16.41%, which indicates the existence of a global collaboration network in this research. The average number of authors per document was 2.71, indicating that most research was conducted collaboratively. The number of keywords used in this research is 699, which gives an idea of the variety of topics or research focuses in this field. The total references used were 9,997, showing the depth of the literature on which this research is based. The average age of the documents or research referred to is 8.47 years, indicating that the research still refers to relatively recent literature. Finally, each document in this field received an average of 11.61 citations, reflecting the level of influence or significance of this research in the academic community.

Figure 3. Main Information regarding Research on Technological Innovation in the Process of Mathematics Learning in the Scopus Database (Analysis with R Program)

Publication Trends from Year to Year

Analysis of publication trends from year to year aims to understand the development and increase in research interest in technology topics in mathematics learning from time to time.

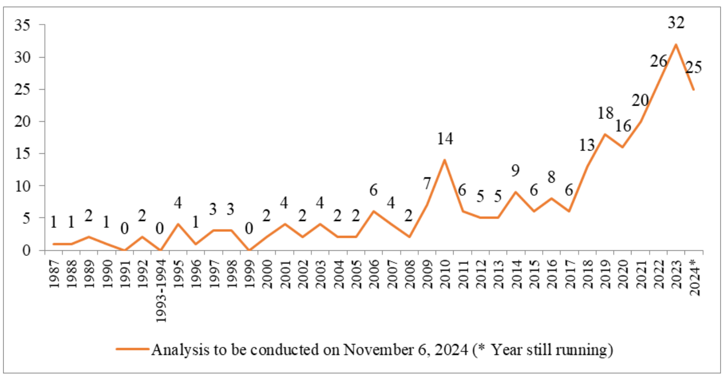

Figure 4. Number of Publications from 1987 to 2024 on the topic on Technological Innovation in the Process of Mathematics Learning (Analysis with R Program)

In Figure 3, it can be seen that there were several years or periods that recorded zero publications, namely 1991, 1993-1994, and 1999. This shows that in this period, attention to technology topics in mathematics learning was still very low, or technology had not developed enough to be widely applied in the field of mathematics education. The lack of publications in these years could also indicate that research in this area had not been a priority, so that few or even no articles were published. Furthermore, it can be seen that the growth in publications from 1987 to 2009 only produced 53 (20.22%) documents, which indicates that during that period interest and research activities on technology in mathematics learning were still limited. However, after 2010, the number of publications increased almost 4-fold, reaching 209 (79.77%) documents, with the peak publication occurring in 2023 at 32 (12.21%) publications. This shows that in the last decade, interest in research in this area has grown rapidly, along with technological advances that are increasingly being adopted in education and the increasing need for technology-based learning innovations in the basis and process of mathematics learning.

The Most Productive and Collaborative Between Countries in the World

The most productive and collaborative between countries analysis aims to identify the countries that are most active in producing publications and establishing collaborations in the field of technology research in mathematics learning.

Table 1. *The Top 10 Most Productive Countries on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	Country	Continent	NP	%	TC	%
1st	United States	North America	37	14.12%	597	33.15%
2nd	Australia	Oceania	13	4.96%	566	31.43%
3rd	China	Asia	12	4.58%	117	6.50%
4th	South Africa	Africa	11	4.20%	60	3.33%
5th	Turkey	Asia	9	3.44%	73	4.05%
6th	United Kingdom	Europe	7	2.67%	100	5.55%
7th	Mexico	North America	6	2.29%	58	3.22%
8th	Canada	North America	5	1.91%	22	1.22%
9th	Kazakhstan	Asia	5	1.91%	6	0.33%
10th	Malaysia	Asia	5	1.91%	41	2.28%

Description: NP= Number of Publications, TC= Total of Citations

Based on the visualization in Figure 5, the international collaboration network shows close connections between several countries in research on technological innovation for mathematics learning. The United States is seen as the center of this collaboration network, showing great influence in research in this area. Around the USA, there are countries such as Canada, Germany and Italy which also have strong connections, forming a large group connected in a global network. On the other hand, there are also small groups such as countries in the Arab region (Saudi Arabia, Kuwait, United Arab Emirates) as well as a European group involving the UK, Finland and Cyprus, which also form a significant collaboration network. This indicates that there is cooperation between countries in strengthening research in the field of educational technology.

This collaboration network is in line with the results in Table 1, where the United States shows a dominant role in publications related to technological innovation in mathematics learning, followed by countries such as Australia, which, although having a smaller number of publications, still makes a significant contribution. North America (which includes the USA, Mexico, and Canada) and Asia (with countries such as China, Turkey, Kazakhstan, and Malaysia) are regions that are active in publications in this field. Contributions from countries on the continent highlight their high involvement in research, while countries from Africa (such as South Africa) and Oceania (Australia) show a strong impact in the global citation network despite a lower number of publications.

The Most Productive Affiliation and Collaboration Between Affiliation

Analysis of the most productive affiliates and collaboration between affiliates aims to identify the most productive affiliates in producing scientific publications. In addition, this analysis also aims to understand collaboration patterns between affiliates who contribute to research related to technological innovation in mathematics learning.

Table 2. *The Top 10 Most Productive Affiliation on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	Affiliation	City	Country	NP	%
1st	Universiti Putra Malaysia	Serdang	Malaysia	9	3.44%
2nd	The University of Queensland	Brisbane	Australia	7	2.67%
3rd	University of KwaZulu-Natal	Durban	South Africa	7	2.67%
4th	University of Pretoria	Pretoria	South Africa	7	2.67%
5th	Johannes Kepler University	Linz	Austria	6	2.29%
6th	The University of Texas at Austin	Austin	United States	6	2.29%
7th	University of Vienna	Vienna	Austria	6	2.29%
8th	Arizona State University	Tempe	United States	5	1.91%
9th	Khmelnytskyi Humanitarian-Pedagogical Academy	Khmelnytskyi	Ukraine	5	1.91%
10th	National and Kapodistrian University of Athens	Athens	Greece	5	1.91%

Description: NP= Number of Publications

Based on Table 2, Universiti Putra Malaysia in Serdang, Malaysia, ranks highest with 9 (3.44%) publications, showing dominance in research related to technological innovation in mathematics learning. Followed by The University of Queensland in Brisbane, Australia, as well as two universities in South Africa, namely the University of KwaZulu-Natal in Durban and the University of Pretoria in Pretoria, each with 7 (2.67%) publications. The presence of two South African universities in the top ranking highlights Africa's significant contribution to this field, alongside the dominance of universities in Asia and Australia.

Overall, institutions from various continents, such as Asia, Africa, Europe and America an active role in this research. Austria has two influential affiliates, namely Johannes Kepler University and the University of Vienna, which demonstrate strong European contributions. Meanwhile, the United States also features productive universities such as The University of Texas at Austin and Arizona State University. Although the contribution of each affiliate in terms of number of publications varies, collectively these universities strengthen global research collaboration and development in technological innovation in mathematics education, highlighting cross-continental relevance in the development of modern educational practices.

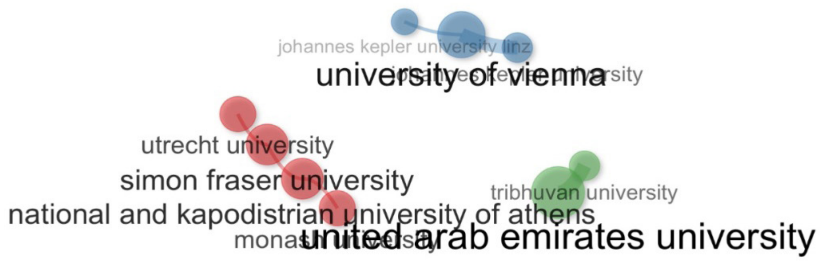

Figure 6. Visualization Results regarding Collaboration between Affiliation in the World on the topic on Technological Innovation in the Process of Mathematics Learning (Analysis with R Program)

In the results from Figure 6, it can be seen that there is a strong pattern of collaboration between universities in various countries in research on Technological Innovation in the Process of Mathematics learning. The University of Vienna, United Arab Emirates University and Simon Fraser University stand out as collaboration centers that attract other universities to work together in this field. This collaboration shows the importance of cross-country synergy in strengthening research and expanding the scope of knowledge. In addition, the involvement of various universities from various regions, such as Europe, Asia and the Middle East, reflects joint efforts to increase the effectiveness on Technological Innovation in the Foundations and Process education. By connecting these institutions, it is hoped that the resulting knowledge and innovation can be spread more quickly and adopted by various parties.

The results in Figure 6 and Table 2 both show the great contribution of a number of universities around the world in advancing research on Technological Innovation in the Process of Mathematics learning. Although Figure 6 highlights the collaborative relationships between universities, while Table 2 shows the most productive institutions based on the number of publications, both illustrate the important role of universities in various parts of the world. Universities in Asia, Africa and Australia, in particular, have shown significant contributions, both through publications and collaborations. This underlines that research in this area is not only productive, but also has a widespread impact through international cooperation.

The Most Productive Researchers

The analysis of the most productive researchers aims to identify individuals who have made major contributions to research related to technological innovation in mathematics learning, based on the impact and quality of their work. In the analysis shown in Table 3, the authors chose to use the h-index as the basis for ranking, rather than just the number of publications, in contrast to Figure 7 depicting overall researcher productivity based on the number of documents and citations. It aims to assess not only the productivity of researchers, but also how often their work is cited by the academic community, reflecting the influence and relevance of research in the field of technology-based mathematics education.

Table 3. *The Top 10 Most Productive Researcher on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	Author	Affiliation	Country	h	TC	NP
1st	Goos Merrilyn	University of the Sunshine Coast	Australia	3	183(10.16%)	3(1.15%)
2nd	Graham Marien Alet	University of Pretoria	South Africa	3	24(1.33%)	4(1.53%)
3rd	Hohenwarter Markus	Johannes Kepler University Linz	Austria	3	18(1.00%)	3(1.15%)
4th	Houghton Tony	Johannes Kepler University Linz	Austria	3	18(1.00%)	3(1.15%)
5th	Kynigos Chronis	National and Kapodistrian University of Athens	Greece	3	27(1.50%)	4(1.53%)
6th	Lavicza Zsolt	Johannes Kepler University	Austria	3	20(1.11%)	4(1.53%)
7th	Mayerhofer Martin	University of Vienna	Austria	3	18(1.00%)	4(1.53%)
8th	Saal Petronella Elize	Human Sciences Research Council	South Africa	3	24(1.33%)	4(1.53%)
9th	Van Ryneveld Linda	University of Pretoria	South Africa	3	18(1.00%)	3(1.15%)
10th	Weinhandl Robert	Johannes Kepler University	Austria	3	18(1.00%)	4(1.53%)

Description: h=h-index, NP= Number of Publications, TC= Total of Citations

Based on the Table 3, the author with the highest number of publications is Goos Merrilyn from the University of the Sunshine Coast, who has 3 publications and a total of 183 citations. However, in terms of distribution of publications, dominance is seen at Johannes Kepler University Linz which has several productive authors, including Hohenwarter Markus, Houghton Tony, Lavicza Zsolt, and Weinhandl Robert, with 3 to 4 publications each. All of these authors have a consistent h-index of 3 and contribute to developing topics related to technology in mathematics learning. Johannes Kepler University's dominance in this list shows the institution's significant contribution to research in this field, both in terms of quality and quantity of publications.

In addition, a number of authors from various universities such as the University of Pretoria and the National and Kapodistrian University of Athens also contributed a no less significant number of publications, with 3 to 4 publications each. This diversity of affiliations indicates strong international collaboration in research on technological innovation in the process of mathematics learning. Overall, these authors, although coming from universities around the world, make important contributions to enriching the literature and strengthening research trends in educational technology, especially those focused on mathematics.

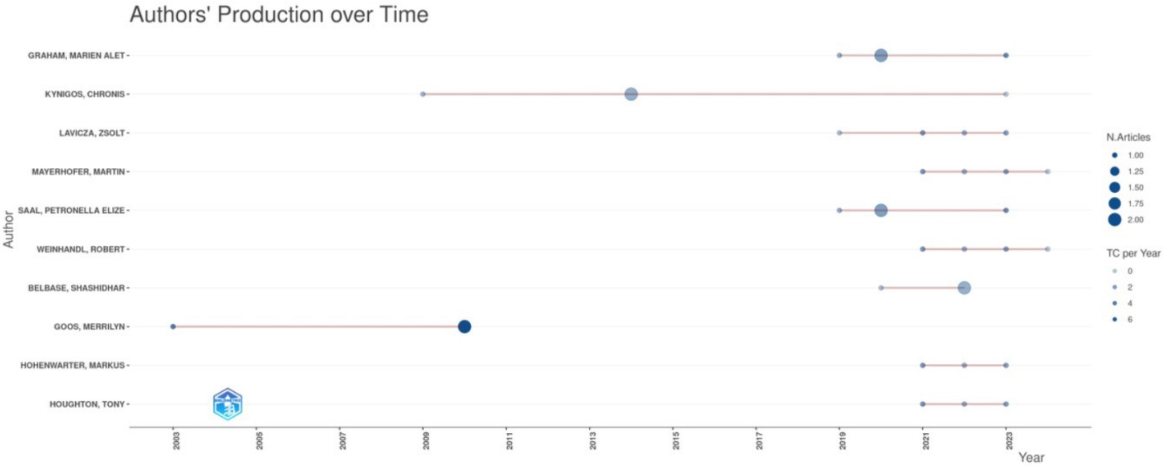

Figure 7. Visualization Results regarding Authors' Production over Time on the topic on Technological Innovation in the Process of Mathematics Learning (Analysis with R Program)

From Figure 7, it can be seen that the production of articles by writers related to research on Technological Innovation in the Process of Mathematics learning has varied over a certain period of time. Some authors, such as Kynigos Chronis and Lavicza Zsolt, show consistency in publications, with contributions spread across several years. There are also authors such as Goos Merrilyn, who have limited but significant production periods in certain years. This visualization shows how each author contributed differently over a period of time, with the size of the circles indicating the number of publications and the color intensity indicating the citation rate per year. This phenomenon indicates differences in patterns of engagement in research, which may reflect a sustained research focus or more sporadic research activities.

The relationship between Figure 7 and Table 3 shows the contribution of authors from several countries, especially from universities in Australia, South Africa and Austria, in publications and citations on the topic on Technological Innovation in the Process of learning. The top authors in Table 3, such as Goos Merrilyn from Australia and several authors from South Africa and Austria, show high contributions to this research, both in terms of publications and citations. A comparison between this figure and table shows how productive writers who have high h-index values not only actively publish but also have significant influence in this field. This linkage emphasizes the importance of the contributions of leading authors from various countries in enriching academic literature and shows the important role of international universities in encouraging collaboration and the dissemination of knowledge.

The Most Productive Source

Productive source analysis aims to identify the journals or publication sources most frequently used by researchers in a particular field. This is important to understand where innovative research in mathematics learning with technology tends to be published, as well as to assess the impact and relevance of these journals in the scientific community.

Table 4. *The Top 10 Most Productive Source on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	Journal Name	SQ	Country[a]	h	TC	NP
1st	Education and Information Technologies	Q1	United States	7	151(8.38%)	12(4.58%)
2nd	Educational Studies in Mathematics	Q1	Netherlands	6	186(10.33%)	9(3.44%)
3rd	Mathematics Education Research Journal	Q1	Netherlands	6	252(13.99%)	7(2.67%)
4th	Computers and Education	Q1	United Kingdom	5	371(20.60%)	5(1.91%)
5th	Eurasia Journal of Mathematics, Science and Technology Education	Q2	Turkey	5	82(4.55%)	7(2.67%)
6th	International Journal of Mathematical Education in Science and Technology	Q2	United Kingdom	4	63(3.50%)	8(3.05%)
7th	ZDM - Mathematics Education	Q1	Germany	4	58(3.22%)	4(1.53%)
8th	British Journal of Educational Technology	Q1	United Kingdom	3	136(7.55%)	3(1.15%)
9th	Computers in the Schools	Q2	United States	3	20(1.11%)	5(1.91%)
10th	Education Sciences	Q2	Switzerland	3	21(1.17%)	6(2.29%)

Description: SQ= Scopus Quartile, a = Country based on origin of Publisher from Source, h=h-index, NP= Number of Publications, TC= Total of Citations

The journal with the highest number of publications came from “Education and Information Technologies” with 12(4.58%) articles and total citations of 151(8.38%). Followed by “Educational Studies in Mathematics” and “Mathematics Education Research Journal”, which despite having fewer articles, showed a significant impact with total citations of 186(10.33%) and 252(13.99%) respectively. The journal with the highest citation impact was “Computers and Education” from United Kingdom, which, despite only having 5(1.91%) publications, managed to get 371(20.60%) citations. This shows that the quality of research published in these journals is highly recognized in the scientific community.

Geographically, the United Kingdom dominates with three influential journals, all of which are ranked Q1, indicating high quality in scientific publications. Q1 journals generally dominate, indicating that research on technological innovation in the process of mathematics learning is published in high-quality sources, with a total of six out of ten journals in this category. Although journals from the United States, Turkey, and Switzerland represent smaller contributions, all of these sources play a role in enriching the global literature, highlighting the importance of international collaboration in this field.

Documents with the Highest Citations

Documents with the highest citations analysis aims to identify works that have had the greatest influence in a particular field, measured by the number of citations received. By understanding these documents, it is possible to recognize their important contributions in directing research and influencing subsequent studies.

Table 5. *The Top 10 Documents with the Highest Citations on the topic on Technological Innovation in the Process of Mathematics Learning*

Rank	Citation	Title	Source	SQ	TC
1st	(Pierce et al., 2007)	A scale for monitoring students' attitudes to learning ….	Computers & Education	Q1	141
2nd	(López, 2010)	The digital learning classroom: Improving ….	Computers & Education	Q1	103
3rd	(Cai et al., 2019)	Tablet-based AR technology: Impacts on students' …	British Journal of Educational Technology	Q1	98
4th	(Barkatsas et al., 2009)	Learning secondary mathematics with technology: Exploring the complex …	Computers & Education	Q1	90
5th	(Roschelle et al., 2010)	Scaffolding group explanation and feedback with …	Educational Technology Research and Development	Q1	90
6th	(Goos et al., 2003)	Perspectives on technology mediated …	The Journal of Mathematical Behavior	Q1	83
7th	(Arroyo et al., 2013)	Gender differences in the use and benefit of …	Journal of Educational Psychology	Q1	69
8th	(Bennison and Goos, 2010)	Learning to teach mathematics with technology: ….	Mathematics Education Research Journal	Q1	60
9th	(Bray and Tangney, 2016)	Enhancing student engagement through the affordances ….	Mathematics Education Research Journal	Q2	59
10th	(Trouche and Drijvers, 2010)	Handheld technology for mathematics ….	ZDM - International Journal on Mathematics Education	Q2	58

Description: SQ= Scopus Quartile in the year of article publication, TC= Total of Citations

The document with the highest number of citations is from Pierce et al, (2007) which discusses various aspects of technology use in mathematics learning, with a diverse focus ranging from student attitudes towards technology to its impact on learning engagement and achievement. The most highly cited article demonstrating the importance of measuring student attitudes towards technology in mathematics was published in the journal "Computers & Education", with 141 citations. This journal dominates the high citation rankings, demonstrating its significant influence in the field of technology education. The large number of citations indicates that these studies make an important contribution to understanding and optimizing the use of technology for mathematics learning.

The majority of the highest-cited documents were published in Q1-ranked journals, confirming that research on technology in mathematics education is of recognized quality and influence in the academic community. Topics covered include the use of devices such as tablets, interactive whiteboards and handheld technology to enhance student understanding and engagement. In addition, research also explores aspects such as gender differences in the benefits of educational technology and professional development needs for teachers. Collectively, these documents contribute to a broader understanding of how technology can be effectively applied to enhance mathematics learning at different levels of education.

After answering all of the first research question (RQ1), the researcher went on to answer the second research question (RQ2) which included an analysis of keyword clustering and keywords novelty that could be recommended for further research in the field on Technological Innovation in the Process of Mathematics learning. This analysis aimed to identify key themes that have been extensively researched as well as finding gaps or areas that still require further exploration. This analysis uses the VOSviewer application with Network Visualization and Overlay Visualization.

Focus Research

In the focus research, the author uses Keyword Occurance ≤ 3 and uses the Network Visualization feature on VOSviewer. So that we get 41 keywords with 6 clusters.

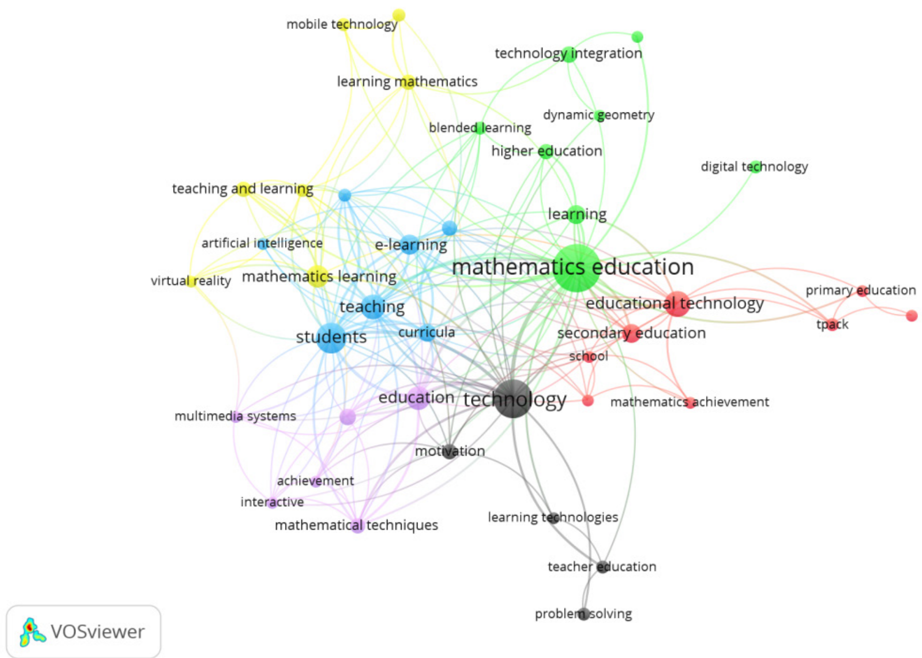

Figure 8. Keyword Grouping on Network Visualization Menu

After clustering with VOSviewer, the author then collects keywords and identifies group names based on the clustering corresponding to the cluster color.

Table 6. *Name Giving Based on Cluster Color Grouping*

Color Name	Keywords	Group Name
Red (8 items/19.51%)	Education Technology, Information Technology, Mathematics Achievement, Mathematics Teachers, Primary Education, School, Secondary Education, TPACK	Learning and Teaching Strategies
Green (8 items/19.51%)	Blended Learning, Digital Technology, Dynamic Geometry, Higher Education, Mathematics Education, Technology Education, Technology Integration	Technology Integration in Education
Blue (7 items/17.07%)	Artificial Intelligence, Curricula, E-learning, Learning Sytems, Mathematics Course, Students, Teaching	Digital Learning Innovations
Yellow (7 items/17.07%)	Augmented Reality, Learning Mathematics, Mathematics Learning, Mobile Technology, Teaching and Learning, Technology Acceptance, Virtual Reality	Immersive and Mobile Learning
Purple (6 items/14.63%)	Achievement, Education, Interactive, Mathematical Technique, Multimedia Systems, Technology Enhanced Learning	Interactive and Multimedia Approaches
Black (5 items/12.19%)	Learning Technologies, Motivation, Problem Solving, Teacher Education, Technology	Pedagogical and Technological Support

Source: VOSviewer

The red cluster titled "Learning and Teaching Strategies" includes keywords that focus on educational technology and how it is applied in the school environment to improve learning outcomes. Elements such as TPACK (Technological Pedagogical Content Knowledge) and the application of information technology are key in designing more meaningful and interactive learning experiences (Tseng et al., 2022). Focusing on primary and secondary education, this cluster underscores the role of teachers in using technology to improve student achievement (Imran et al., 2023). This is particularly relevant to technological innovation in mathematics learning, as teachers need to integrate technological knowledge with effective mathematics teaching methods (Bakar et al., 2020). This cluster highlights the importance of a holistic understanding between technology education and pedagogy to support more modern and adaptive teaching.

The green cluster entitled "Technology Integration in Education" highlights the application of technologies such as blended learning, digital technology, and dynamic geometry in higher education. These technologies play an important role in creating flexible and interactive learning environments, which support technology-based learning in mathematics. This cluster emphasizes the importance of technological innovations that foster more adaptive and integrated teaching, allowing students to access a variety of digital resources and engage in deeper learning (Haleem et al., 2022). This integration provides new opportunities for developing mathematics curricula that are more relevant to the needs of the times and helps connect theory and real-world applications.

The blue cluster entitled "Digital Learning Innovations" focuses on advanced technologies such as artificial intelligence, e-learning, and customized learning systems. These innovations play a role in creating curricula that can be adapted to the individual needs of students, as well as developing interactive and dynamic learning platforms (Tapalova and Zhiyenbayeva, 2022). In the context of math learning, the application of AI and e-learning systems can help simplify complex concepts and improve student understanding (Akugizibwe and Ahn, 2020). This cluster highlights the huge potential of digital technology to revolutionize the way students learn mathematics, and how technology can support more personalized and effective teaching.

The yellow cluster entitled "Immersive and Mobile Learning" covers technologies such as augmented reality, virtual reality and mobile devices that are changing the way students engage with math learning materials. These technologies create a more immersive and visual learning experience, which is particularly beneficial in teaching abstract concepts in math (Su et al., 2022). Acceptance of the technology by students is also a focus, as the implementation of these advanced tools requires readiness on the part of both students and teachers. Innovations like these allow math learning to be more engaging and interactive, and help students understand the material in a way that is more intuitive and connected to the real world.

The purple cluster entitled "Interactive and Multimedia Approaches" focuses on multimedia systems and interactive techniques designed to enhance technology-based learning. The use of technology-enabled systems for mathematics learning enriches students' experiences with a variety of visual and dynamic representations of mathematical concepts (Flood et al., 2020). This cluster highlights how interactivity and multimedia-enriched learning can make mathematics more engaging and accessible to different types of learners. With technology supporting personalized learning, this approach contributes to innovation in developing students' ability to understand mathematics more thoroughly.

The black cluster entitled "Pedagogical and Technological Support" discusses motivation, learning technology, problem solving and teacher education. This cluster focuses on how technology can be used to support teachers in developing teaching skills and creating learning environments that motivate students to think critically and creatively (Henriksen et al., 2021). In the context on Technological Innovation in the Process of Mathematics learning, this aspect is important to ensure that technology is not only used as a tool, but also as a medium that facilitates effective teaching strategies. By supporting teachers through appropriate training and technological resources, mathematics learning can become more meaningful and encourage students to be actively engaged.

Keywords Novelty

The keyword novelty analysis aims to identify new keywords that have emerged in recent research related to technological innovation in mathematics learning. These new keywords can be recommended for future research to explore relevant and under-discussed topics and encourage the development of innovative ideas in the field.

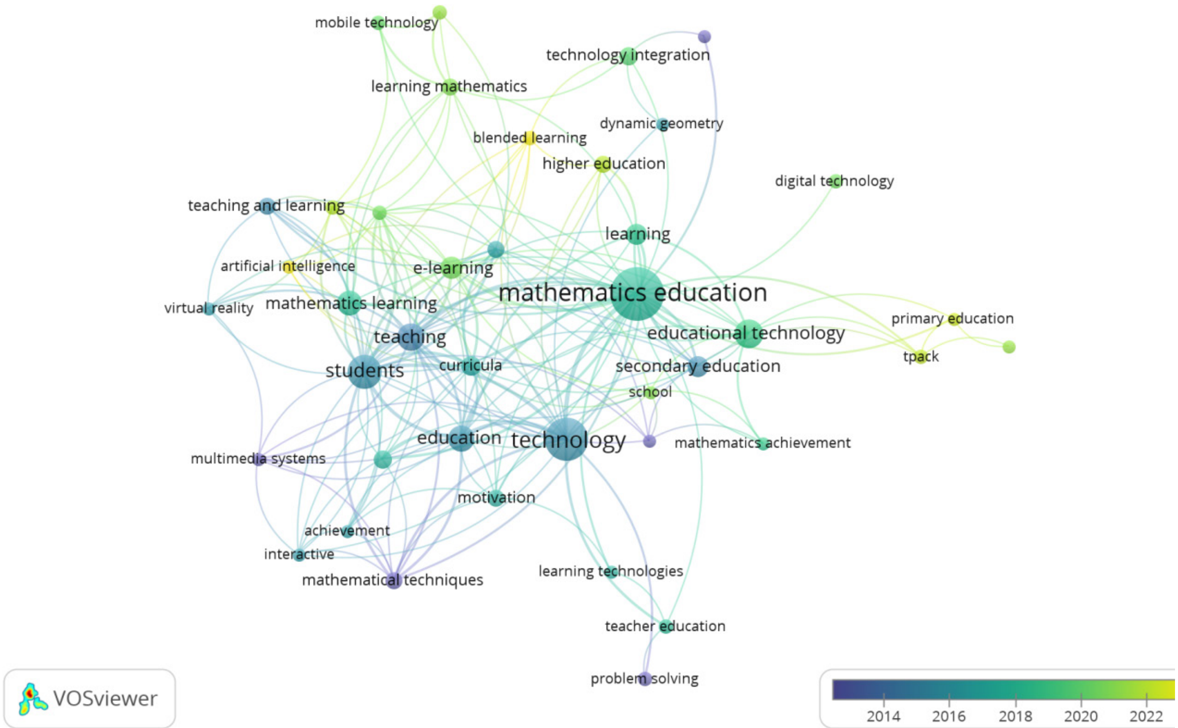

Figure 9. Keyword Novelty Analysis with Overlay Visualization on VOSviewer

The overlay visualization analysis shows that the light-colored keywords indicate that the keywords began to be used in the most recent year and can be used as recommendations for future research related to technological innovation in mathematics learning. The keywords “Artificial Intelligence” and “Blended Learning” are yellow keywords, indicating that these two concepts are newly used in technological innovation in mathematics learning. This suggests a new trend in the incorporation of advanced technology and more flexible learning methods, which may encourage further innovation in this area.

Discussions

The development of education after war has undergone significant transformation, with many countries working to rebuild education systems to support social and economic recovery (Behnamnia et al., 2020). Schools play an important role in the intellectual and social development of children, by providing formal education and shaping character to face future challenges (Tsekhmister, 2022). However, challenges such as limited facilities and resources still exist, which affect students’ learning experiences. Therefore, attention to supportive school and classroom conditions is essential to create an effective learning atmosphere. In this context, technology has an important role in mathematics learning innovation, as it can optimize the learning process, introduce more adaptive methods, and create a more inclusive learning environment, allowing students from different backgrounds to learn more easily and enjoyably.

The development of technological innovations in mathematics learning showed significant growth from 1987 to 2024, with a total of 262 documents published. Since 2010, publications have increased rapidly, especially by 2023, indicating a growing interest driven by technological advances and the need for technology-based learning innovations. The United States and Australia lead in the number of publications and citations, demonstrating their great influence in this field. North America and Asia make significant contributions to global research, with smaller contributions from other continents such as Africa and Oceania, but with considerable citation impact. Overall, these countries play a key role in advancing technological innovation in mathematics learning, both through their research output and global academic influence. One challenge in global collaboration is the disparity in technological infrastructure between developing and developed countries, where access to necessary hardware and software for technology-based mathematics education is limited in resource-constrained areas. However, this also presents an opportunity to create more cost-effective, accessible technology solutions, with developed countries providing technical support and sharing knowledge to help overcome these challenges.

Universiti Putra Malaysia showed dominance in producing publications focused on this topic, followed by other leading universities in Australia and South Africa. The dominance of universities from Asia and Australia is also evident, reflecting the great influence of these regions in developing and applying technology in mathematics learning. On the other hand, Johannes Kepler University Linz emerged as a very productive institution with many authors who contributed significantly to the development of this topic. Their contributions, both in terms of number of publications and quality of research, illustrate the importance of this institution in research related to mathematics education technology, as well as showing the global trend of increasing interest in technology-based learning innovations.

Journals from different countries, especially those listed in the Q1 category, showed great contribution in advancing knowledge about the application of technology in mathematics education. Although the number of publications varies, some journals with few publications have attracted attention due to their high citation impact, confirming that quality of research takes precedence over quantity. In addition, the highly cited articles, which address aspects such as the use of technological tools and gender differences in the benefits of educational technology, provide valuable insights to improve the effectiveness of mathematics learning. Overall, research in this area continues to grow and make a significant contribution to understanding how technology can be applied to improve mathematics learning at different levels of education.

In the clustering of keywords, various aspects on Technological Innovation in the Process of Mathematics learning were revealed. The application of technology in primary and secondary education is important to improve student achievement, with attention to the integration of technological and pedagogical knowledge. Technologies such as blended learning and dynamic geometry enable flexible and interactive learning environments in higher education. In addition, artificial intelligence and e-learning help create personalized curricula to facilitate student understanding. The use of augmented reality and mobile devices also makes learning more immersive. Multimedia systems and interactive techniques enrich the math learning experience, while support for teachers helps create more effective teaching.

Overlay Visualization analysis shows that the keywords “Artificial Intelligence” and “Blended Learning” are emerging as new trends in technological innovation in mathematics learning. “Artificial Intelligence” has the potential to create a more personalized learning experience, by automatically customizing materials and providing feedback. Meanwhile, “Blended Learning” enables flexible math learning by combining face-to-face and online methods, giving students the freedom to learn at their own pace. Both concepts represent new directions in education and could be the focus of future research to improve the effectiveness of math learning.

Trends in technological innovation in the process of mathematics learning show that Artificial Intelligence and Blended Learning are increasingly becoming the main focus of educational innovation in mathematics. The use of AI, such as on the Matific platform, provides math exercises based on games for K-6 students, utilizing AI to adjust the difficulty level and provide automatic feedback. Microsoft Copilot helps students understand math formulas through step-by-step explanations, improving conceptual understanding and critical thinking skills. Applications like Photomath and Microsoft Math Solver use AI to allow students to solve math problems by providing step-by-step solutions and detailed explanations. Furthermore, future research could propose automatic assessments to measure student engagement and success in AI-based mathematics learning. This includes developing algorithms to evaluate student interaction with the AI system, such as problem-solving speed, error rates, and progress from one learning session to another. The results of this evaluation could be used to provide more tailored learning recommendations based on individual student needs and identify areas that require improvement in the technology-based learning process.

Meanwhile, Blended Learning combines face-to-face and online learning, offering students flexibility in managing their time and learning methods. E-learning platforms enable students to practice math problems online and see their results immediately, helping them better understand the material. Online discussions on platforms like Google Classroom allow students to share their views on complex topics such as quadratic equations. Video tutorials enable students to learn independently about basic math concepts. The integration of AI and Blended Learning in the mathematics curriculum creates a personalized and flexible learning experience, enhances motivation and student engagement, and bridges gaps in diverse learning needs.

Conclusions

From the analysis, it can be concluded that research on technological innovation in the process of mathematics learning started in 1987 and experienced significant growth until 2024, with a surge in publications occurring since 2010, especially in 2023. Countries such as the United States and Australia lead in the number of publications and citations, demonstrating their great influence in this field, followed by significant contributions from the Asian and North American regions. Universiti Putra Malaysia, along with leading universities in Australia and South Africa, showed dominance in publications related to this topic. Some Q1 journals also play a major role in advancing knowledge about technology in mathematics education, with the quality of research taking precedence over the quantity of publications. Keyword clustering revealed that technological trends such as “Artificial Intelligence” and “Blended Learning” are now emerging as new directions in technological innovation for mathematics learning, offering a more personalized and flexible approach to improve learning effectiveness in the future.

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Conflict of interests

The authors declare no conflict of interest.

Author Contributions

S: Conceptualization, Writing - Original Draft, Editing and Visualization; HR: Review & Editing, Formal analysis, and Methodology; ZE: Validation and Supervision; ZA: Writing – Review & Editing; RH: Validation and Supervision. All authors have read and agreed to the published version of the manuscript.

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