

Dynamic Software in Mathematics Education Scoping Review and Bibliometric Analysis (ScoRBA)

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Abstract

This study investigates the research trends of dynamic software in mathematics education through a bibliometric analysis using data from the Scopus database spanning from 2011 to 2025. A total of 203 articles were selected after a systematic filtering process based on subject area (mathematics), document type (article), language (English), and final publication stage. The analysis was conducted using RStudio and VOSviewer to visualize publication growth, contributing journals, prolific authors, productive institutions, country distribution, and keyword co-occurrence networks. Results indicate a significant upward trend in publications, particularly from 2023 onwards. The International Journal of Mathematical Education in Science and Technology emerged as the most productive journal with 28 articles. Stupel, M. was identified as the most prolific author with 6 publications. China and the United States led in national contributions. Keyword network analysis revealed three major research clusters: computational mathematics, nonlinear dynamic systems, and dynamic geometry software in mathematics education. GeoGebra and dynamic geometry software were the most frequently explored themes. Research gaps were identified in areas such as the integration of dynamic software with computational thinking, adaptive learning, and primary school contexts.

INTRODUCTION

Dynamic software in mathematics education refers to interactive digital tools that allow learners to manipulate mathematical objects and observe changes in real time. These tools can support visualization, exploration, conjecture formation, experimentation, and connections among multiple mathematical representations. GeoGebra and related dynamic geometry software (DGS) are among the most widely studied platforms because they enable learners to investigate geometric relationships that may remain abstract in static diagrams (Gurmu et al., 2024; Yohannes & Chen, 2021).

Previous research has established that DGS research has expanded across geometry, algebra, calculus, problem solving, teacher education, and technology-enhanced learning. However, the literature has not developed evenly. Earlier reviews found that studies were concentrated on GeoGebra, secondary and higher education, student achievement, conceptual understanding, and attitudes toward technology (Ondes, 2021; Yohannes & Chen, 2021). Recent bibliometric studies have further mapped GeoGebra-specific publication patterns, productive countries, institutions, journals, and keyword clusters (Acikgul & Keskin, 2025; Awaji et al., 2025). These studies demonstrate the value of science mapping, but they also reveal that existing reviews are divided by software platform, database, time period, and methodological approach. Consequently, the claim that no bibliometric study has ever examined this field is too broad. The more defensible problem is that no sufficiently integrated mapping has yet examined the broader dynamic-software literature in mathematics education across a consistent Scopus-based period while simultaneously tracing its intellectual, geographical, institutional, and thematic development.

Research on teacher knowledge provides an important perspective for understanding this problem. The Technological Pedagogical Content Knowledge (TPACK) framework established that meaningful technology integration requires more than technical competence or access to digital tools. It depends on the situated interaction of technological, pedagogical, and mathematical knowledge (Mishra & Koehler, 2006). In dynamic geometry environments, teachers must interpret what dragging, multiple representations, invariance, measurement, and software constraints make mathematically visible. They must also decide how to orchestrate these affordances so that students move from visual experimentation toward generalization, explanation, and proof. Bretscher's study illustrates this complexity by showing that teachers' knowledge involves managing transitions within dynamic geometry software and between digital and paper-and-pencil environments (Bretscher, 2023). Nevertheless, much of this literature is based on small-scale case studies, professional-development projects, or specific software tasks. It therefore provides rich accounts of teacher expertise but limited evidence about how teacher knowledge appears across the field as a whole.

Research on curriculum reform has likewise established that the introduction of digital tools does not automatically produce instructional change. Digital curriculum resources are adapted, selected, and redesigned through use; therefore, curriculum design continues during classroom enactment (Pepin et al., 2017). Similarly, Clark-Wilson and Hoyles identified gaps between curriculum design, teachers' written plans, and actual classroom practice (Clark-Wilson & Hoyles, 2019). These gaps arise from teachers' confidence, pedagogical knowledge, institutional support, available time, classroom contingencies, and the need to respond to unexpected events. Such findings challenge technology-centered accounts that treat software as an independent driver of reform. They instead position teachers, curriculum materials, assessment expectations, and school conditions as mutually connected elements of implementation.

Despite these advances, important limitations remain. First, research on DGS effectiveness often reports positive outcomes without sufficiently explaining how teacher knowledge, task design, classroom orchestration, or curriculum conditions produced those outcomes (Ondes, 2021; Clark-Wilson & Hoyles, 2019). Second, teacher-knowledge studies explain the expertise required for technology integration but rarely show whether these concerns are central, emerging, or marginal within the wider research field (Bretscher, 2023; Ondes, 2021). Third, curriculum-reform studies document implementation difficulties but are usually situated in particular programmes, countries, or school systems (Clark-Wilson & Hoyles, 2019; Erfjord, 2016). Finally, existing bibliometric studies tend to emphasize publication counts, citation impact, or platform-specific trends rather than examining whether the field is moving from technology adoption toward questions of teacher learning, curriculum enactment, equity, and sustainable reform (Awaji et al., 2025; Acikgul & Keskin, 2025). Bibliometric analysis is therefore valuable not because it replaces pedagogical research, but because it can expose the structure, visibility, and development of these research priorities (Ellegaard & Wallin, 2015; Zupic & Čater, 2015).

This gap is significant because publication growth may create the impression of a mature field while leaving central implementation questions unresolved. Without an integrated account of who is producing knowledge, where that knowledge is produced, which journals and institutions shape the field, and how themes such as teacher knowledge and curriculum reform are connected, researchers may interpret increasing publication volume as evidence of pedagogical progress. The present study addresses this problem through a bibliometric analysis of Scopus-indexed research on dynamic software in mathematics education published from 2011 to 2025. Specifically, it examines (1) annual publication growth, (2) leading journals, (3) most productive authors, (4) most contributing institutions, (5) country-level contributions, and (6) keyword co-occurrence networks and research clusters. Particular attention is given to whether teacher knowledge, professional development, curriculum reform, and classroom implementation emerge as prominent or underdeveloped themes. By doing so, the study provides a field-level evidence base for identifying established research patterns, inconsistencies, neglected perspectives, and future directions in dynamic software research in mathematics education.

METHOD

Research Design

This study adopts the ScoRBA (Scoping Review and Bibliometric Analysis) design to map the development, scope, and structure of scientific literature on dynamic software in mathematics education. This integrated approach combines the systematic mapping and gap-identification strengths of scoping reviews with the quantitative analysis of publication trends, collaboration networks, citation patterns, and thematic clusters offered by bibliometrics (Börner et al., 2003; Ellegaard & Wallin, 2015; Hallinger & Kovačević, 2019; Kartika et al., 2023). The approach is appropriate because research on dynamic software spans multiple disciplines and has generated a substantial and diverse body of literature. Using Scopus-indexed bibliometric data, the study proceeds through five stages: research design, data collection, data analysis, visualization, and interpretation.

Bibliometric Data Collection

The data collection stage was carried out through a systematic search of the Scopus database as the primary data source. Scopus was chosen because it has 70% wider literature coverage than other data sources and is widely used in previous bibliometric research related to mathematics education. The search was conducted using the keywords: (TITLE-ABS-KEY(dynamic software) AND TITLE-ABS-KEY("mathematics")) AND PUBYEAR > 2010 AND PUBYEAR < 2026, with a limitation on the time span 2011–2025 (the last 15 years). The 15-year span was chosen to enrich the data, considering that publications generally cite references from the previous 10 years. The filtering process was carried out in stages: first, 1,315 articles were obtained; second, filtered based on the type of article document and English language to 593 articles; third, filtered based on relevant fields of study (mathematics, arts and humanities, psychology, and multidisciplinary), leaving 203 articles for analysis.

Data Analysis and Visualization

Bibliometric data analysis was conducted using two main software tools: RStudio (Bibliometrix package) and VOSviewer. Scopus provides initial data on the number of publications, indexed journal sources, influential authors, and productive institutions. However, more in-depth bibliometric analysis requires additional software. Therefore, this study used RStudio and VOSviewer to analyze and visualize bibliographic data using bib and RIS data.

RStudio was chosen because it offers more comprehensive analysis results, including general article information, annual publication growth trends, analysis of productive authors and institutions, and various bibliometric statistical visualizations (Kartika et al., 2023). Meanwhile, VOSviewer was chosen for its capabilities in producing network visualizations, overlay visualizations, and density visualizations, which facilitate the interpretation of collaboration patterns and thematic clusters in dynamic software research in mathematics education. The complementary use of these two software tools allows for a more in-depth and comprehensive analysis in accordance with the ScoRBA approach used.

The complete search strategy and data collection flowchart are presented in Table 1. In the first stage, a search using primary keywords yielded 1,315 articles related to dynamic software and mathematics in general. In the second stage, filtering based on document type (article), language (English), and source type (journal) yielded 593 articles. In the third stage (final screening), articles irrelevant to the fields of mathematics, arts and humanities, psychology, and multidisciplinary were eliminated, leaving 203 articles selected for bibliometric analysis in this study.

Table 1
Data collection flow diagram

Bibliometric Data Compilation:	Analyzing dynamic software in journal articles related to mathematics education that contain "dynamic software AND mathematics" in the title, abstract, or keywords from 2011 to 2025
Search Query:	(TITLE-ABS-KEY (dynamic software) AND TITLE-ABS-KEY ("mathematics")) AND PUBYEAR > 2010 AND PUBYEAR < 2026
Results:	A total of 1,315 articles related to dynamic software and mathematics in general were found.
Data Filtering 1:	Additional filtering on the search string to focus only on the article document type, written in English and journal source type
Search Query:	(TITLE-ABS-KEY (dynamic software) AND TITLE-ABS-KEY ("mathematics")) AND PUBYEAR > 2010 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))
Results:	A total of 593 articles related to dynamic software and mathematics in general were successfully found.
Data Filtering 2:	Additional filtering of the search string to focus only on relevant subject areas: mathematics, arts and humanities, psychology, and multidisciplinary. Removed articles that were not relevant to dynamic software research in mathematics education (such as in subject areas: computer science, engineering, health professions, etc.)
Search Query:	(TITLE-ABS-KEY (dynamic software) AND TITLE-ABS-KEY ("mathematics")) AND PUBYEAR > 2010 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SUBJAREA, "MATH")) AND (LIMIT-TO (PUBSTAGE, "final"))
Results:	A total of 203 articles remained for analysis.

RESULTS AND DISCUSSION

General Information and Growth Trends

The data from Scopus in this study covers the period from 2011 to 2025 (the last 15 years) because general citations in articles must come from publications at least ten years previously (Kartika et al., 2023; Phan et al., 2022). However, the researchers added another five years to the 15-year period to allow for a more comprehensive analysis of the data. Furthermore, numerous articles on dynamic software in mathematics education have been published in the past 15 years, making this data sufficient for analysis. Figure 1 presents general information from 203 articles published between 2011 and 2025.

Figure 1 shows that the total number of articles sourced from the Scopus database is 203, limited to the field of mathematics (Mathematics), the type of article document (Article), and the final publication stage. The data source in this study comes from only one reference, namely journal articles from the Scopus database. Based on the data obtained, research on dynamic software in mathematics education has shown a significant growth trend from year to year.

Based on Fig. 1, article publications fluctuate but show an overall upward trend. Publications began being indexed in 2011 with 14 articles, then decreased in 2012 to 8 articles. Articles fluctuated in the range of 8 to 15 articles per year from 2012 to 2022, with peaks in 2015 and 2017 with 15 articles each. A significant spike occurred starting in 2023 with 21 articles, increasing to 22 articles in 2024, and then to 19 articles in 2025. These data indicate that research on dynamic software in mathematics education has become a topic of increasing interest among researchers (Gökçe & Guner, 2021; Zhang et al., 2025), and needs to be continuously developed through ongoing research and publication.

Contributions by Journal

Various journals contribute to publishing articles related to dynamic software in mathematics education. Figure 2 shows the distribution of the top five journals publishing the most articles based on Scopus data.

Based on Fig. 2, Scopus-indexed journal sources publish topics related to dynamic software in mathematics education. The International Journal of Mathematical Education in Science and Technology (IJTP) had the highest number of publications with 28 articles, followed by the Journal of Mathematical Behavior (9 articles), BMC Bioinformatics (7 articles), the International Journal of Bifurcation and Chaos (6 articles), and Mathematics (6 articles). Although there are many other journal sources, these five journals have the highest number of published articles. Table 2 presents a breakdown of the top five journals.

Table 2
Top Five Journals

Journal Name	CiteScore	Percentile	% Quoted	SJR	Publisher	Number of Articles
International Journal of Mathematical Education in Science and Technology	3.6	Q1 (82%)	72	0.658	Taylor & Francis	28
Journal of Mathematical Behavior	3.9	Q1 (84%)	74	0.701	Elsevier	9
BMC Bioinformatics	5.2	Q1 (88%)	79	0.912	Springer Nature	7
International Journal of Bifurcation and Chaos	2.8	Q2 (74%)	65	0.487	World Scientific	6
Mathematics	2.3	Q1 (79%)	61	0.418	MDPI	6

Table 2 displays the top five journals publishing articles related to dynamic software in mathematics education. The International Journal of Mathematical Education in Science and Technology (IJMEST) was the most productive journal, publishing 28 articles, far surpassing all other journals. Published by Taylor & Francis, this journal is a Q1 journal highly relevant to the study of dynamic software in the context of mathematics education (Phan et al., 2022). The Journal of Mathematical Behavior, published by Elsevier, ranked second with 9 articles, followed by BMC Bioinformatics (7 articles), and the International Journal of Bifurcation and Chaos and Mathematics, each with 6 articles. These journals can serve as references for researchers focusing on dynamic software studies in mathematics education to publish their articles (Ha et al., 2020; Julius et al., 2021).

Contributions by Author

Hundreds of authors from various countries contributed to this research. Figure 3 displays the distribution of the top 10 authors who have published the most articles in the field of dynamic software in mathematics education, based on Scopus data.

Based on Fig. 3, the most influential author in dynamic software research in mathematics education is Stupel, M., with 6 articles. This shows that Stupel is a very productive researcher and can be used as a primary reference in dynamic software research in mathematics education (Kartika et al., 2023). Stupel's research focus is the use of dynamic software, particularly dynamic geometry software, in the exploration and proof of mathematical theorems at various levels of education.

The second most-authored is Caglayan, G. with 5 articles, which focus on the application of dynamic software in interactive learning of algebra and geometry. Next, Li, Z. published 4 articles focusing on the integration of dynamic software in mathematics learning in higher education. Other authors such as Chehlarova, T., Korn, J., Ruthven, K., and Zengin, Y. each published 3 articles. Authors

Abdullah, A.H., Baki, A., and Ben-Chaim, D. each published 2 articles. The diversity of institutional affiliations of these authors reflects the global nature of the study of dynamic software in mathematics education.

Contributions by Institution

Hundreds of university affiliates from various countries are identified in the Scopus data. Figure 4 shows the distribution of the top 10 universities contributing the most published articles in the field of dynamic software in mathematics education.

Figure 4 displays the most productive universities in publishing articles related to dynamic software in mathematics education. The university with the most contributions is Shaanan Academic Religious Teachers College with 6 articles. This aligns with Stupel, M.'s position as the most prolific author affiliated with that institution (Kartika et al., 2023).

The top ten universities are Shaanan Academic Religious Teachers College (6 articles), Institute of Mathematics and Informatics (4 articles), The Bulgarian Academy of Sciences (4 articles), Chengdu University (4 articles), Atatürk University (3 articles), Pennsylvania State University (3 articles), University of South Florida Tampa (3 articles), Florida International University (3 articles), Dicle University (3 articles), and Chongqing University (3 articles). These findings demonstrate an even distribution of contributions from institutions across countries, reflecting the broad scope of dynamic software research in mathematics education globally (Gökçe & Guner, 2021).

Distribution by Country

A total of 35 countries contributed to the publication of this article. Figure 5 shows the distribution of the top 10 countries publishing the most articles in dynamic software research in mathematics education, as well as a comparison between Single-Country Publication (SCP) and Multiple-Country Publication (MCP).

Based on Fig. 5, the most prominent finding is that China is the most productive country with around 37 articles, surpassing the United States, which is in second place with around 36 articles. This fact shows that researchers from China and the United States are very active in studying the application of dynamic software in mathematics learning, reflecting the strong research infrastructure and educational technology in both countries (Gökçe & Guner, 2021; Suseelan et al., 2022).

The next ranking is Turkey (around 20 articles), the United Kingdom (around 14 articles), Germany (around 12 articles), Spain (around 11 articles), Canada (around 9 articles), Israel (around 8 articles), India (around 6 articles), and Sweden (around 6 articles). When viewed by publication type, most dynamic software research from various countries is the result of cross-country collaboration (MCP), which indicates a strong culture of international collaboration in dynamic software research in the field of mathematics education (Gökçe & Guner, 2021). This finding provides an opportunity for researchers from countries that have not yet contributed much, including Indonesia, to increase international collaboration in dynamic software research (Suseelan et al., 2022).

Keyword and Term Analysis

Based on the results of keyword analysis of 203 articles using VOSviewer, there are 44 keyword items with 3 main clusters and 321 links with a total link strength of 728 (Börner et al., 2003). The most frequently occurring words were trees (mathematics) (29 times), dynamic geometry software (28 times), bifurcation (27 times), software, algorithms, numerical methods, mathematics education, nonlinear equations, visualization, and teaching. Figure 6a displays the visualization of the keyword network using VOSviewer.

Figure 6a shows a keyword network indicating the interrelationships between research themes. There are three main interconnected clusters. The red cluster includes core keywords such as trees (mathematics), software, algorithms, parameter estimation, dynamic models, humans, human, article, and simulation, which represent the general theme of mathematical computing and software (Chaudhary et al., 2015; Murariu et al., 2025). The green cluster includes themes such as bifurcation (mathematics), nonlinear equations, chaos, chaotic systems, Lyapunov methods, solitons, computer software, and bifurcation analysis, which represent the study of dynamic mathematics and nonlinear systems (Gilson et al., 2003; Li et al., 2024a; Rahaman et al., 2025). The blue cluster includes the themes of dynamic geometry software, mathematics education, teaching, mathematics, visualization, and dynamic software, which represent the core of the use of dynamic software, especially in the context of mathematics education (Gurmu et al., 2024; Schoenherr et al., 2024; Zhang et al., 2025).

Based on Fig. 6b, dynamic geometry software and dynamic software are closely related to several research themes in other clusters, such as mathematics education, teaching, geometry, dynamic geometry software, GeoGebra, problem solving, and visualization (Gurmu et al., 2024; Zhang et al., 2025). In addition, the dynamic software theme is also related to GeoGebra and problem solving alone (Phan et al., 2022). Themes directly related to dynamic software indicate that there are already publications that examine the interrelationships between these themes in depth. Meanwhile, the link between dynamic software and themes in the green cluster, such as nonlinear equations and bifurcation analysis, is still relatively weak, indicating that the integration of dynamic software in the study of nonlinear systems remains open to further exploration (Li et al., 2024a; Nasir et al., 2025).

Thus, the next trend in dynamic software research is themes that are not yet directly connected, such as the integration of dynamic software with project-based learning approaches, the use of dynamic software in online learning, and the use of dynamic software at the elementary education level (Schoenherr et al., 2024; Zhang et al., 2025). Although some of these themes have been published, the number is still very small, so there is still a great opportunity for follow-up in future research.

Figure 7a (Overlay Visualization) shows the trend of keyword occurrences based on time spanning from 2016 to 2022, where lighter colors (yellow) indicate newer research, while darker colors (blue/purple) indicate older research (Börner et al., 2003). Based on the overlay visualization, the trending and emerging themes in recent research (approaching 2022) include: bifurcation analysis, nonlinear equations, solitons, Lyapunov methods, and chaotic systems (Li et al., 2024a; Nasir et al., 2025). Meanwhile, themes that have been researched for a long time but are still relevant include trees (mathematics), algorithms, software, dynamic geometry software, and mathematics education, which tend to have darker colors indicating their earlier emergence within the time span.

Figure 7b (Density Visualization) shows the level of research density on each theme, where lighter colors (yellow-green) indicate more research has been conducted, while darker colors (dark blue) indicate themes that have been little researched and are research opportunities (Aslan Tutak et al., 2011). The themes of trees (mathematics), bifurcation (mathematics), and dynamic geometry software and mathematics education have the highest density, indicating that these themes are the most studied (Schoenherr et al., 2024; Zhang et al., 2025). Meanwhile, themes such as the integration of dynamic software with computational thinking, adaptive learning based on dynamic software, and the specific use of dynamic software at the elementary school level have received relatively little research, thus opening up opportunities for researchers to explore further.

The research trends in dynamic software in mathematics education that can be identified from this analysis are: (1) the use of dynamic geometry software in learning geometry and mathematical visualization, especially through software such as GeoGebra and Cinderella (Gurmu et al., 2024; Zhang et al., 2025), (2) the use of dynamic software in the study of nonlinear systems, bifurcation, and chaos mathematics (Carrizosa et al., 2021; Li et al., 2024b; Nasir et al., n.d.), (3) dynamic software integration to support mathematics learning at higher education level, especially calculus and algebra (Schoenherr et al., 2024), (4) utilization of dynamic software in the development and visualization of algorithms and numerical methods (Murariu et al., 2025), and (5) the application of dynamic software to improve understanding of mathematical concepts through a visual and interactive approach. Research on dynamic software that links aspects of computational thinking and adaptive learning with mathematical concepts is still very limited, thus providing very promising research opportunities for further research.

Author	Article Title	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
Red Cluster						
(Chaudhary et al., 2015)	A mathematical model for the conservation of forestry biomass with an alternative resource for industrialization: a modified Leslie Gower interaction	Mathematical modeling of forest biomass population dynamics using a system of nonlinear differential equations with age structure (pre-mature and mature trees) and industrialization variables. This article represents the use of dynamic software for numerical simulation and analysis of complex mathematical systems in an applied context.	The model successfully analytically proves the existence of four biologically feasible equilibrium points using Pontryagin's Maximum Principle for optimal control. The use of dynamic software for numerical simulations allows visual and interactive verification of analytical results, strengthening the understanding of differential equation concepts and stability theory.	The article does not explicitly discuss the use of dynamic software as a mathematics learning tool. Numerical simulations are conducted without pedagogical guidance for classroom use. There is no exploration of how similar models can be visualized using GeoGebra or other dynamic software to support the learning of calculus and differential equations.	The mathematical model in this article can be used as a real-world problem-based learning context for topics such as differential equations, optimal control, and sensitivity analysis. Dynamic software such as GeoGebra or Maple can be used to interactively visualize solution trajectories and equilibrium point bifurcations in applied mathematics courses.	Develop a dynamic software-based learning module for the topic of nonlinear differential equations using the context of a similar biomass model. Design a study on the effectiveness of dynamic simulation (GeoGebra/Maple) in improving students' understanding of the concepts of equilibrium points and stability analysis. Integrate such applied models into a STEM-based mathematics curriculum.
(Murariu et al., 2025)	Trends and Applications of Principal Component Analysis in Forestry Research: A Literature and Bibliometric Review	A comprehensive bibliometric review of Principal Component Analysis (PCA) applications in forestry research (1993–2024) using VOSviewer for knowledge network visualization. This article represents the usage patterns of bibliometric analysis and data visualization software as part of dynamic software in applied mathematics research.	The use of VOSviewer as dynamic visualization software for bibliometric mapping has proven effective in identifying research clusters and evolving scientific trends. This approach aligns with the methodology used in the main article, demonstrating how dynamic software can be integrated into big data-driven mathematical and statistical research.	The article does not discuss the potential use of interactive dynamic software (such as GeoGebra or R Shiny) to visually teach PCA concepts to students. There is no pedagogical guidance on how to dynamically visualize PCA dimensionality reduction. Exploration of PCA as a statistical mathematics learning material using dynamic software is still very limited.	The VOSviewer bibliometric methodology used in this article can be adapted as a learning model for mathematical data analysis in statistics classes. The visualization of keyword co-occurrence networks provides a concrete example of the application of dynamic software to analyze and present complex data interactively for academic purposes.	Develop an interactive PCA learning module based on R Shiny or GeoGebra that allows students to explore dynamic data projections. Design a study on the effectiveness of dynamic visualization in learning linear algebra concepts (eigenvalue, eigenvector) that underlie PCA. Integrate VOSviewer-based bibliometric analysis as a research practicum in a mathematics research methodology course.
(Carrizosa et al., 2021)	Mathematical optimization in classification	A comprehensive study of mathematical optimization	The MILO formulation produces more accurate	The article doesn't explore the use of	The concepts of classification and	Develop an interactive applet based on GeoGebra or

Author	Article Title	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
Red Cluster						
	and regression trees	formulations (Continuous Optimization and Mixed-Integer Linear Optimization/MILO) for constructing globally optimal classification and regression trees. This article presents the use of algorithms and numerical methods that can be visualized using dynamic software in discrete mathematics and optimization learning.	decision trees than the traditional greedy approach (CART, C4.5). The use of dynamic software to visualize the step-by-step decision tree construction process can strengthen students' understanding of the concepts of combinatorial optimization and integer linear programming.	dynamic software as a learning tool for decision tree and optimization concepts in mathematics classes. Interactive visualization of the MILO optimization process using software like GeoGebra or Python Jupyter isn't discussed. There's no discussion of how students can explore the trade-off between tree accuracy and complexity visually and dynamically.	regression trees in this article can serve as an engaging learning context for topics such as optimization, linear programming, and mathematical logic. Dynamic software such as Python (Scikit-learn + visualization) or R can be used to interactively demonstrate the process of building decision trees to mathematics and statistics students.	Desmos to dynamically visualize the process of node splitting in a decision tree. Design a study on the effectiveness of interactive visualization of decision tree optimization in improving students' understanding of linear programming. Integrate a dynamic software-based decision tree exploration project into a Discrete Mathematics or Introduction to Machine Learning course.

Author	Article Title	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
Green Cluster						
(Rahaman et al., 2025)	Bifurcation, chaos, modulation instability, and soliton analysis of the Schrödinger equation with cubic nonlinearity	Nonlinear dynamical analysis of the Schrödinger equation with cubic nonlinearity includes bifurcation, chaos, modulation instability, and soliton solutions. This article represents the use of dynamic software (such as Mathematica or MATLAB) for phase portrait visualization, Runge-Kutta simulation, and analysis of nonlinear dynamical systems in the context of advanced mathematics.	Identifying various types of soliton solutions (bright, dark, kink, anti-kink, periodic) and chaotic behavior through 2D/3D phase portrait visualization using dynamic software. The use of computationally based 4th-order Runge-Kutta demonstrates how dynamic software enables the numerical exploration of systems that do not have closed analytical solutions.	The article does not address the pedagogical potential of visualizing nonlinear dynamic systems using more accessible software (such as GeoGebra or GNUpot) for students. The simulations only use advanced commercial software without guidance on how to implement it in a mathematics learning context. There is no exploration of how phase portraits and bifurcations can be explained interactively in the classroom.	The phase portrait and bifurcation visualizations from this article can be replicated using dynamic software such as GeoGebra (CAS) or MATLAB for teaching dynamic systems in universities. The dynamically visualized Lyapunov exponent and chaos concepts provide mathematics students with an intuitive understanding of the sensitivity of initial conditions and the uncertainty of nonlinear systems.	Developing an interactive applet based on GeoGebra or Desmos to dynamically visualize phase portraits and bifurcations of nonlinear differential equations for students. Designing a dynamic system learning module based on dynamic software that integrates Runge-Kutta numerical simulations with visual exploration. Examining the effectiveness of dynamic chaos visualization on understanding the concepts of stability and sensitivity in the Differential Equations course.
(Li et al., 2024b)	Bifurcations, chaotic behavior, sensitivity analysis and new optical solitons solutions of Sasa-Satsuma equation	Bifurcation analysis, chaotic behavior, and sensitivity of the Sasa-Satsuma equations using the $\exp(-Y(\zeta))$ -expansion method to generate new optical soliton solutions. This article represents a pattern of using computational dynamic software to explore nonlinear solutions and visualize system dynamics through phase portraits and Poincaré maps interactively.	The $\exp(-Y(\zeta))$ -expansion method yields a new family of soliton solutions including singular complexitons and periodic solitons. The use of the Lyapunov Exponent (LLE = 0.12) as a quantitative proof of chaos demonstrates how dynamic computational software enables in-depth analysis that is not possible purely analytically, opening up opportunities for visual exploration for advanced mathematics students.	The article does not discuss the use of more accessible dynamic software for teaching bifurcation and chaos concepts in the classroom. Visualizations of chaotic attractors and Poincaré maps are only available through advanced computing software without pedagogical guidance. There is no exploration of how students can independently replicate these nonlinear system	The concept of solitons and chaotic solutions visualized through phase portraits can be a rich learning material for Dynamical Systems and Differential Equations courses in higher education. Dynamic software such as MATLAB or Python (Matplotlib) can be used to interactively reproduce visualizations of bright/dark solitons and chaotic attractors, deepening students' understanding of nonlinear behavior.	Developing a nonlinear system learning module based on dynamic software (Python/GeoGebra) that allows students to explore bifurcation and chaos visually. Designing a comparative study between understanding the concept of solitons using dynamic visualization versus conventional methods. Examining the effectiveness of interactive phase portrait simulations in helping students understand the concepts of stability and initial condition sensitivity in the Differential Equations course.

Author	Article Title	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
Green Cluster				visualizations using GeoGebra or Python.		
(Nasir et al., n.d.)	Dynamical study of different types of soliton solutions with bifurcation, chaos and sensitivity analysis to the non-linear coupled Schrödinger model	A comprehensive dynamic study of various types of soliton solutions of the nonlinear Schrödinger equation coupled with bifurcation, chaos, and sensitivity analysis. This article represents a pattern of intensive use of dynamic software for multi-method analysis: phase portrait, fractal dimension, Lyapunov exponent, Poincaré map, and modulation instability in one integrated research framework.	Presenting the most comprehensive chaos analysis using seven detection tools simultaneously: fractal dimension, return map, power spectrum, recurrence diagram, Lyapunov exponent, strange attractor, and basins of attraction. The integration of all these chaos detection tools into interactive dynamic software could be a breakthrough in the learning of nonlinear dynamic systems in higher education.	All chaos analyses were conducted using advanced computational software without any discussion of its accessibility for learning. There was no discussion of how students could use more affordable dynamic software to explore similar concepts. The pedagogical potential of multi-tool chaos detection visualization for advanced mathematics education remains unexplored.	The collection of dynamic visualizations (phase portraits, Poincaré maps, and strange attractors) in this article can be used as a reference for designing learning activities for nonlinear dynamic systems. Educators can adapt this multi-tool chaos detection approach into a dynamic software-based (MATLAB/Python) lab to develop students' understanding of the complexity of nonlinear systems in a deep and visual way.	Developing an interactive applet based on dynamic software that integrates multiple chaos detection tools (Lyapunov exponent, phase portrait, Poincaré map) in a single interface for learning purposes. Designing a curriculum for a Nonlinear Dynamic Systems course that utilizes interactive simulations based on Python or MATLAB. Examining the impact of using multi-perspective chaos visualization on the understanding of the concepts of sensitivity and uncertainty in advanced mathematics students.

Author	Article Title	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
Blue Cluster						
(Schoenherr et al., 2024)	Learning with visualizations helps: A meta-analysis of visualization interventions in mathematics education	A meta-analysis of 20 years of research on GeoGebra as a dynamic visualization tool on student mathematics achievement. Focusing specifically on GeoGebra as the sole software and analyzing moderators such as topic, duration, and sample size.	Provides a comprehensive quantitative synthesis over two decades: GeoGebra had a medium-to-large positive effect (Hedges' $g = 0.653$) on mathematics achievement. Three significant moderators were identified: topic (calculus and geometry were more effective), intervention duration (< 4 weeks was more effective), and sample size (< 50 students produced a larger effect).	Only 14 studies with 19 effect sizes met the criteria, making the database relatively small. Most studies did not explicitly report the learning theory underlying the intervention. Long-term effects (retention) are not checked because all studies only measured outcomes immediately after the intervention.	GeoGebra has been consistently shown to improve mathematical comprehension, particularly in geometry and calculus. Shorter intervention durations (under 4 weeks) yield greater effects. Smaller class sizes (under 50 students) optimize GeoGebra's effectiveness.	Research on the cognitive mechanisms that explain why dynamic visualization is effective is urgently needed. Studies using eye-tracking, cognitive load analysis, or think-aloud can open up the learning process. Longitudinal research with a 3–6 month follow-up after the intervention will provide a more complete picture.
(Gurmu et al., 2024)	Effects of GeoGebra-assisted instructional methods on students' conceptual understanding of geometry	Meta-analysis of visualization interventions in general (not just GeoGebra) focuses on mathematics. Involving 41 studies with a total of 10,562 participants, covering both analog and digital visualizations.	Expanding understanding by demonstrating that the effectiveness of visualization ($g = 0.504$) holds across mathematics topics. Both digital and analog media are equally effective, challenging the assumption that technology is always superior. Effects on proximal outcomes are greater than distal outcomes, and positive effects persist through the delayed posttest.	Limitations on variations focus on measurement — only a few studies used standardized tests. As many as 88% of the effect sizes came from basic and secondary education, so the representation focuses on very minimal height. The mediator between the use of visualization and learning outcomes could not be explored.	Analog visualization (pencil and paper) can be just as effective as digital visualization—an important message for schools with limited access to technology. The way instruction is delivered matters more than the mere presence or absence of technology.	Almost all studies focus on intermediate and elementary school. Research on the effectiveness of GeoGebra focusing on high school, especially for calculus, linear algebra, and statistics, is still very limited. Cultural and economic contexts also present interesting research opportunities.
(Zhang et al., 2025)	Dynamic visualization by GeoGebra for mathematics learning: a meta-analysis of 20 years of research	A quasi-experimental empirical study directly testing the effectiveness of GeoGebra combined with collaborative versus	GeoGebra with collaboration (Cohen's $d = 0.82$) was significantly more effective than GeoGebra with conventional methods ($d =$	The quasi-experimental design (not completely randomized) has the potential to introduce selection bias. The sample	Using GeoGebra with collaborative methods (group discussions, exploration) produces a much deeper conceptual understanding.	Opportunities for more systematic comparative research on pedagogical methods—comparing GeoGebra + inquiry-based learning, GeoGebra +

Author	Article Title	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
Blue Cluster						
		conventional methods on 10th-grade students in Ethiopia in understanding geometry.	0.60), and both were better than conventional methods alone ($d = 0.21$), proving that the way technology is integrated determines learning outcomes.	was drawn from only one city in Ethiopia (Shambu), so generalizability is very limited. There was no delayed posttest to measure long-term retention.	Teacher training should focus not only on software operation, but on collaborative learning design.	problem-based learning, and GeoGebra + collaborative learning. Research exploring how teachers' technological pedagogical competencies (TPACK) moderate the effectiveness of GeoGebra interventions.

CONCLUSION

This bibliometric study analyzed 203 Scopus-indexed articles on dynamic software in mathematics education published between 2011 and 2025. The results show a clear upward trend in publications, particularly since 2023, indicating growing research interest in this field (Gökçe & Guner, 2021; Zhang et al., 2025). International Journal of Mathematical Education in Science and Technology, Stupel, M., and Shaanan Academic Religious Teachers College were identified as the most productive journal, author, and institution (Kartika et al., 2023; Phan et al., 2022). China and the United States dominate national contributions, while keyword analysis reveals three main research clusters (Börner et al., 2003). Future research needs to fill the identified gaps, particularly in the integration of dynamic software with computational thinking, adaptive learning approaches, and the context of elementary education (Lepore, 2024; Schoenherr et al., 2024). Researchers from developing countries, including Indonesia, are encouraged to establish international collaborations to strengthen their contributions in this growing field (Suseelan et al., 2022).

Implications for Research and Practice

Implications for Research

Publication growth indicates that dynamic software research is moving beyond early technology-adoption studies toward a more diversified agenda. Earlier work focused mainly on GeoGebra, geometry learning, achievement, and student perceptions, whereas current trends include nonlinear systems, bifurcation, chaos, calculus, algebra, algorithms, and numerical methods. This expansion creates opportunities to examine how different mathematical domains require distinct forms of dynamic representation, interaction, and teacher mediation. Future research should move beyond asking whether software improves achievement. Greater attention is needed to how students interpret variation and invariance, formulate conjectures, connect visual and symbolic representations, and progress from experimentation to explanation and proof. Such studies would clarify how dynamic software supports mathematical understanding.

The findings also highlight the importance of teacher knowledge and classroom orchestration. Visualization alone does not ensure meaningful learning. Teachers need technological, pedagogical, and mathematical knowledge to select tasks, anticipate student strategies, manage software affordances and constraints, and connect exploration with formal reasoning. Research should therefore examine teachers' planning, questioning, orchestration, and professional learning in authentic classrooms.

China and the United States are the most productive countries, with approximately 37 and 36 publications, respectively. This pattern suggests strong research capacity but may also reflect differences in funding, indexing, institutional incentives, and collaboration networks. Comparative research should examine whether priorities from highly productive countries transfer to diverse curricula, languages, infrastructures, and teacher-education systems, while giving greater attention to underrepresented regions. Finally, future studies should combine bibliometric mapping with systematic reviews, meta-analyses, qualitative classroom research, design-based research, and mixed-methods investigations. Bibliometric analysis can identify emerging themes and influential networks, but it cannot explain how software is used in classrooms or why implementation succeeds in one context and fails in another. Linking publication trends with classroom evidence would produce a more complete account of the field's development.

Implications for Practice

For mathematics teachers, the findings support the use of dynamic software as a tool for exploration rather than merely as a digital replacement for static diagrams. GeoGebra, Cinderella, and similar platforms can be used to help students manipulate figures, test conjectures, investigate patterns, visualize functions, explore algorithms, and connect graphical, numerical, and symbolic representations. These activities should be tied to explicit mathematical goals and followed by discussion, justification, and formalization. Teacher education and professional development should therefore focus on pedagogical use rather than software operation alone. Teachers need opportunities to design technology-rich tasks, anticipate student responses, interpret unexpected screen events, and connect dynamic observations to mathematical definitions and theorems. Professional learning should also address classroom management, assessment, accessibility, and the limitations of software-generated representations.

Also, the findings are particularly relevant to higher education, where dynamic software can support calculus, algebra, numerical methods, nonlinear systems, and algorithm visualization. University instructors can use interactive models to make abstract processes visible and allow students to explore parameter changes and complex systems. However, dynamic visualization should complement—not replace—symbolic reasoning, analytical methods, proof, and numerical interpretation.

Curriculum designers should embed dynamic software within coherent sequences of tasks rather than treating it as an optional add-on. Digital resources must be adapted to local curriculum goals, assessment systems, student backgrounds, and available infrastructure. Research on curriculum enactment shows that teachers modify resources during use, meaning that successful implementation depends on teacher design capacity and institutional support. Finally, schools and universities should address equity and sustainability. Effective implementation requires reliable devices, technical support, teacher training, accessible software, and time for collaborative planning. Low-bandwidth, mobile-friendly, multilingual, and inclusive resources may be necessary in contexts where access to advanced technology is uneven. Overall, the study suggests that the future value of dynamic software will depend less on continued publication growth than on whether research and practice connect technological innovation with teacher expertise, curriculum coherence, and meaningful mathematical learning.

Declarations

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable

Competing interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

AI Usage Disclosure

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Author's Contribution

HH: Conceptualisation, Writing - Original Draft, Methodology, Investigation and Visualisation;

Availability of data and material

Data would be made available upon reasonable request.

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Figures

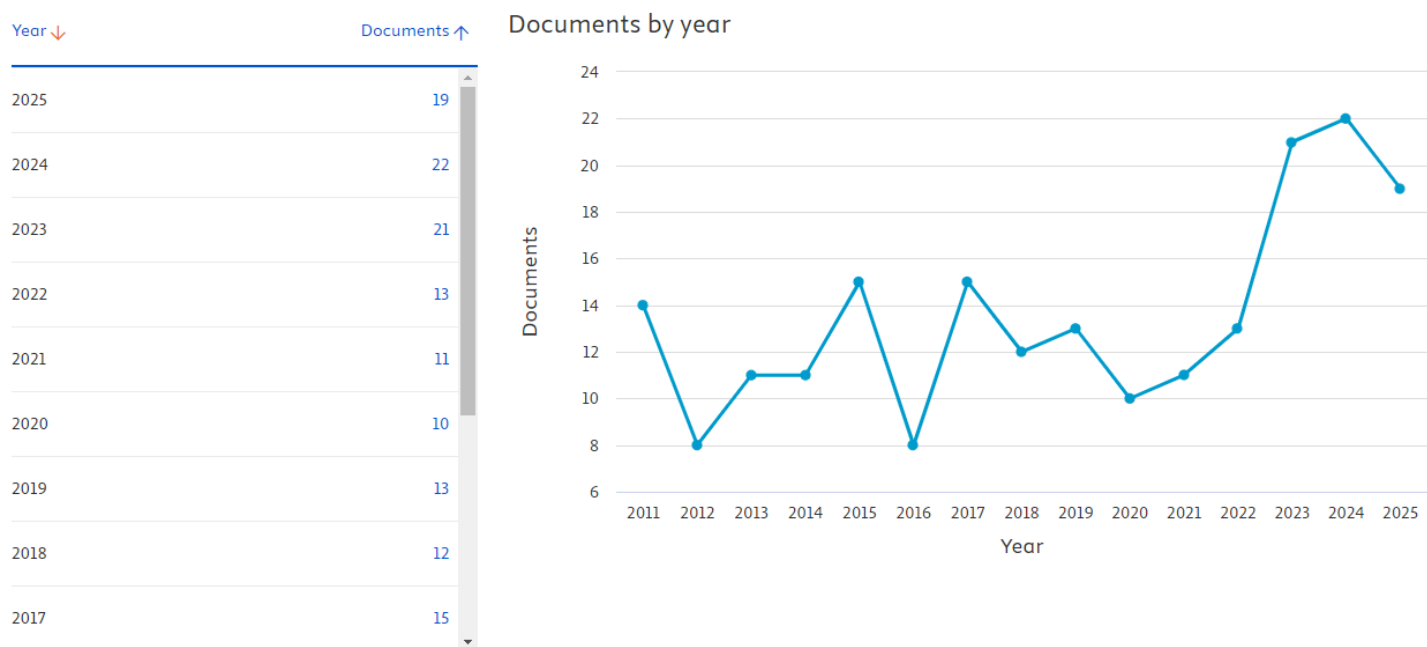


Figure 1

Growth Trend of Article Publications per Year (2011–2025)

Documents per year by source

Compare the document counts for up to 10 sources. [Compare sources and view CiteScore, SJR, and SNIP data](#)

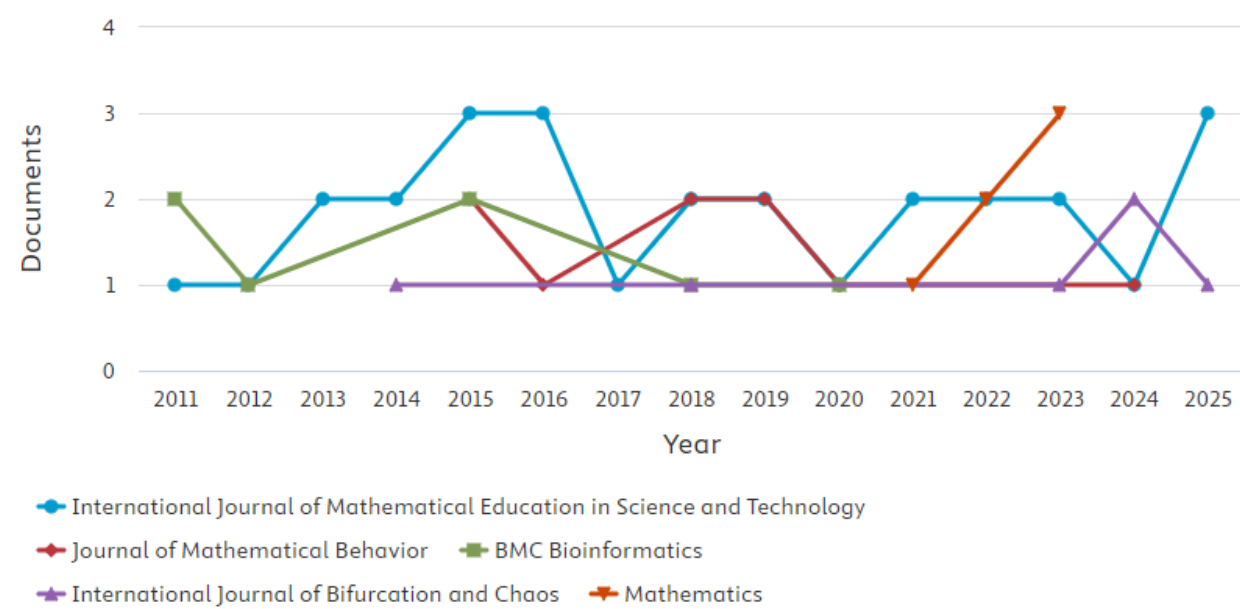


Figure 2
Distribution of Articles Based on Journal Source (Production per Year)

Documents by author

Compare the document counts for up to 15 authors.

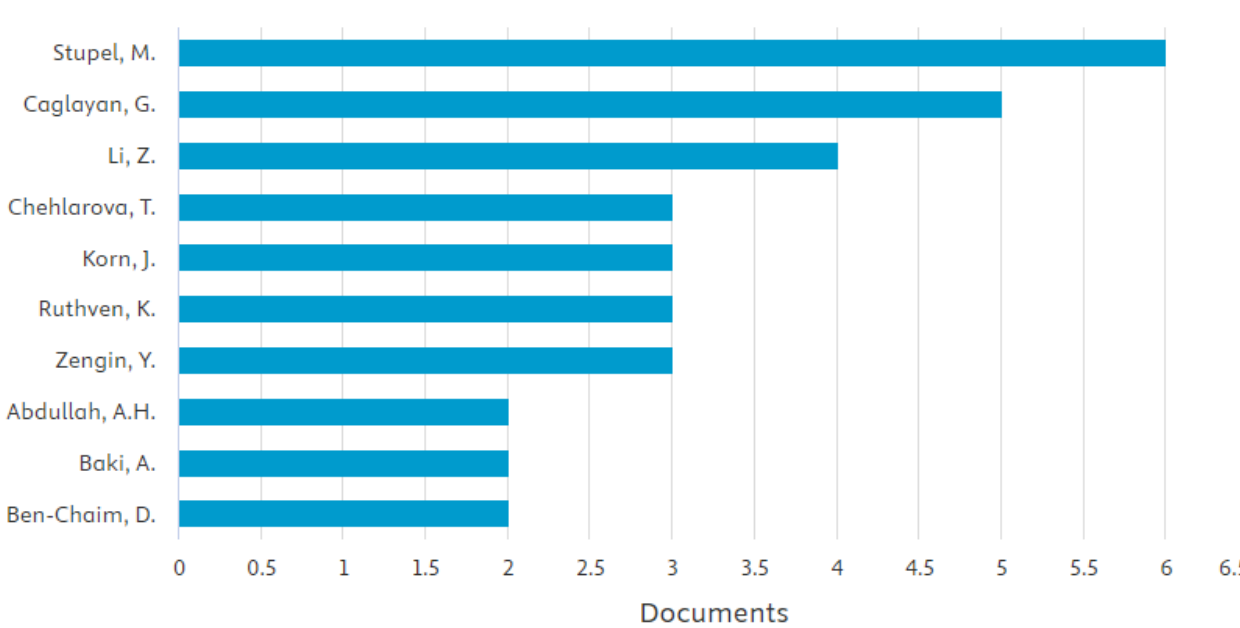


Figure 3
Distribution of Articles by Author (Top 10)

Documents by affiliation

Compare the document counts for up to 15 affiliations.

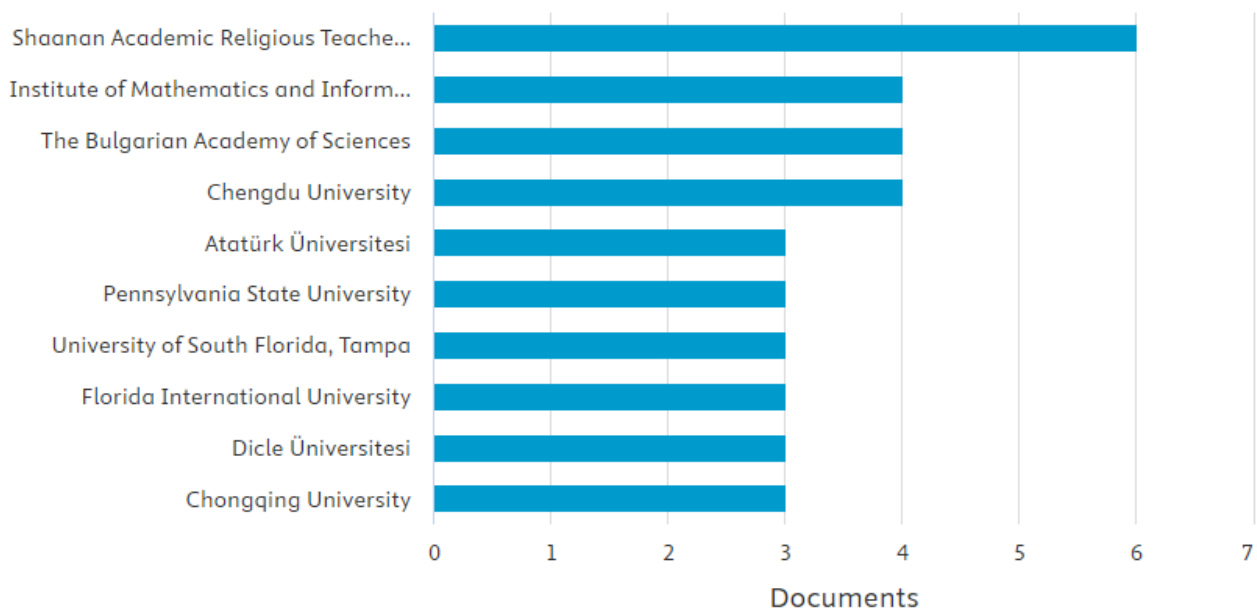


Figure 4
Distribution of Articles by University (Top 10)

Documents by country or territory

Compare the document counts for up to 15 countries/territories.

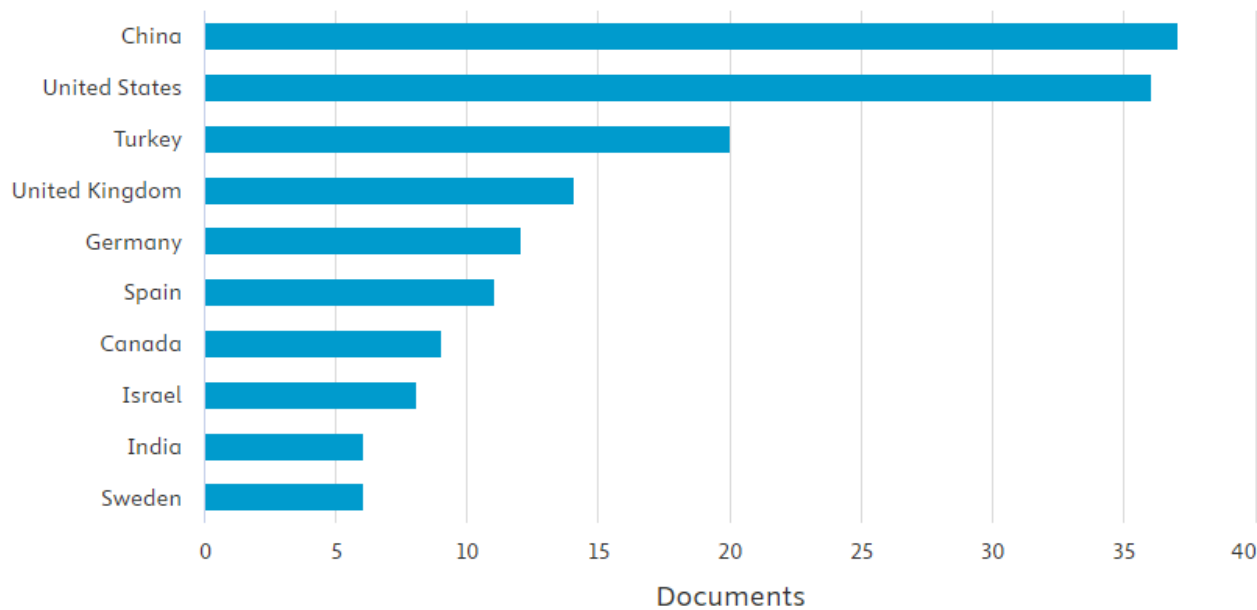


Figure 5
Distribution of Articles by Country and Publication Type (SCP vs MCP)

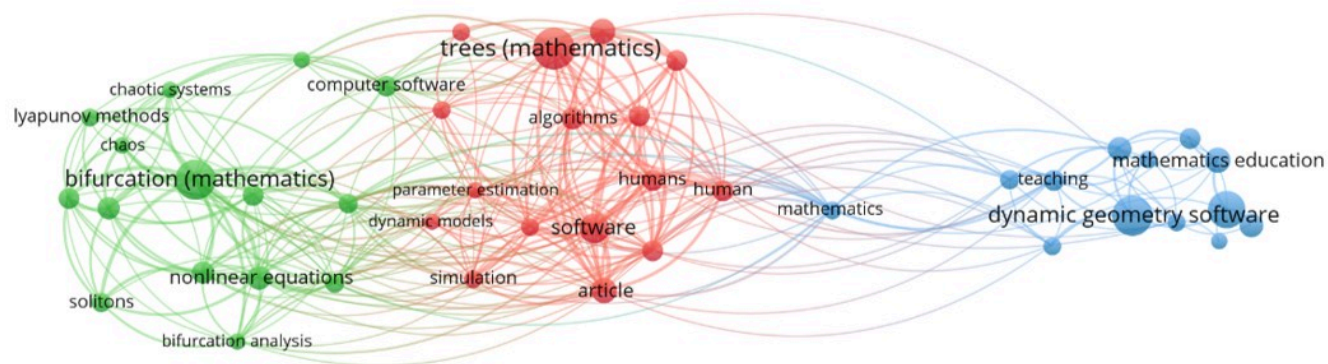


Figure 6a: Visualization of Keywords network

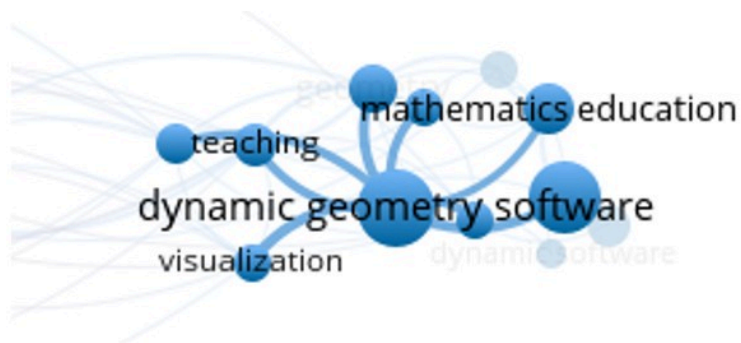


Figure 6b: Visualization of Network with Other Research Clusters

Figure 6

See image above for figure legend

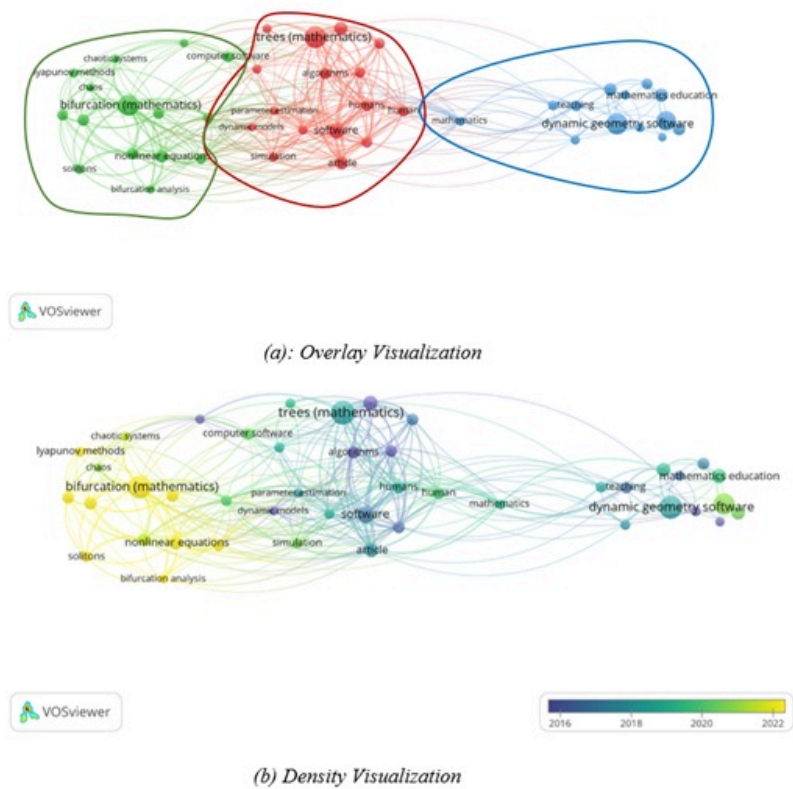


Figure 7

(a) Overlay Visualization and (b) Density Visualization