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ANALYZING TRENDS AND EMERGING PATTERNS IN TEACHING METHODS FOR CALCULUS: A VOSVIEWER-BASED BIBLIOMETRIC APPROACH

ANÁLISE DE TENDÊNCIAS E PADRÕES EMERGENTES EM MÉTODOS DE ENSINO DE CÁLCULO: UMA ABORDAGEM BIBLIOMÉTRICA BASEADA NO VOSVIEWER

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ABSTRACT

This study aims to clarify emerging trends and models in the teaching methods of Calculus by analyzing bibliographic data. The research utilizes the Scopus database in combination with analytical tools such as VOSviewer and CiteSpace, to construct a knowledge map, analyze author collaborations, and identify key research topics. The results of the analysis provide valuable insights into the development trends of Calculus teaching methods, highlight the main research topics, and examine the distribution of influence among authors in the field. These findings offer a deeper understanding of the evolution of teaching methods for Calculus, emphasizing the changes and improvements made to address the increasing learning demands of students. Based on these insights, practical recommendations are proposed to support educators, researchers, and policymakers in enhancing teaching effectiveness and developing training strategies that align with global educational trends.

Keywords: Calculus Education, Teaching Methods, Bibliometric Analysis, VOSviewer, Educational Trends.

RESUMO

Este estudo visa esclarecer tendências e modelos emergentes nos métodos de ensino de Cálculo por meio da análise de dados bibliográficos. A pesquisa utiliza o banco de dados Scopus em combinação com ferramentas analíticas como VOSviewer e CiteSpace para construir um mapa de conhecimento, analisar colaborações de autores e identificar tópicos de pesquisa importantes. Os resultados da análise fornecem insights valiosos sobre as tendências de desenvolvimento dos métodos de ensino de Cálculo, destacam os principais tópicos de pesquisa e examinam a distribuição de influência entre autores no campo. Essas descobertas oferecem uma compreensão mais profunda da evolução dos métodos de ensino de Cálculo, enfatizando as mudanças e melhorias feitas para atender às crescentes demandas de aprendizagem dos alunos. Com base nesses insights, recomendações práticas são propostas para apoiar educadores, pesquisadores e formuladores de políticas no aprimoramento da eficácia do ensino e no desenvolvimento de estratégias de treinamento que se alinhem às tendências educacionais globais.

Palavras-chave: Educação em Cálculo, Métodos de ensino, Análise Bibliométrica, Visualizador VOS, Tendências Educacionais.

Introduction

The study analyzes emerging trends and models in teaching calculus, exploring the integration of visualization methods, interactive mathematical software, and visual problem-solving models. These approaches aim to enhance learners' understanding and engagement

Research Context

Calculus: A Foundational Subject and Teaching Challeng

Calculus is a fundamental and essential subject in mathematics, playing a critical role in undergraduate education (Haspekian, 2005). Its significance is not confined to pure mathematics but extends across various scientific fields. Mastery of calculus concepts is a key determinant for students pursuing careers in science, technology, engineering, and mathematics (STEM) disciplines (Neslihan Bulut et al., 2024). Proficiency in calculus provides a solid foundation, enabling students to engage with advanced courses and tackle complex real-world problems.

However, teaching calculus effectively remains a significant challenge. Instructors must continually innovate and adapt their methods to meet the diverse learning needs of students (Siti Maryam Rohimah, 2025). The rapid advancement of

technology, progress in pedagogical research, and differences in student learning styles require constant updates and improvements in teaching approaches (Elyakim Nova Supriyedi Patty et al., 2024).

The continuous development of teaching methods.

Technology Integration: Modern teaching methods increasingly incorporate technology through digital tools and resources to enhance learning outcomes (Nilza Humaira Salsabila, 2024). Mathematical software, simulation applications, and online learning platforms not only help visualize abstract concepts but also provide instant feedback, facilitating personalized learning and enabling students to progress at their own pace. (Roberto Torres et al., 2024).

New pedagogical insights: Research in learning science and educational psychology has provided key insights into how students process and learn mathematics. Modern teaching methods emphasize active learning, problem-solving, and critical thinking development, rather than focusing solely on formulas and procedures (Vale Isabel's Lab, 2023; Van De Tran et al., 2024). This approach enables students to master concepts while developing creative thinking skills applicable to real-world scenarios (Rivaldo Paul Telussa et al., 2024).

Meeting students' evolving needs: Educators are increasingly recognizing the importance of adapting teaching methods to meet the diverse learning needs, preferences, and experiences of students (Tran Viet Cuong et al., 2021). Learner-centered approaches, collaborative learning, and group projects are implemented to engage students, encourage active participation, and create a supportive learning community, thereby enhancing educational quality (Siti Maryam Rohimah, 2025).

Analysis of emerging trends and models in Calculus teaching methods

Recent studies have identified emerging trends in calculus teaching, especially within the STEAM (Science, Technology, Engineering, Arts, and Mathematics) education framework (Rafael Julius et al., 2021). Muwen Tang (2025) emphasizes that perceptions of usefulness and subjective norms are pivotal in shaping mathematics teachers' intentions to integrate STEAM education. Timothy

Teo (2024) illustrates that changes in teachers' attitudes and perceptions can significantly influence the adoption of modern teaching methods and new technologies. Additionally, Win Phyu Thwe (2024) examines continuous learning intentions within STEAM education, revealing that a combination of students' attitudes, motivation, and perceptions fosters sustained and proactive learning. These studies offer critical insights into developing integrated teaching models that promote deeper student engagement in calculus learning.

Additionally, several studies address specific challenges in calculus teaching and novel approaches to enhancing students' mathematical competence. Rosmawati Mohamed (2020) reports a decline in research on mathematical proficiency in recent years, highlighting a gap that requires attention in teaching methodology improvements. In contrast, Senad Orhani (2024) utilized deep learning to identify issues in calculus applications, paving the way for modern technology integration to improve teaching effectiveness. These studies underscore the necessity of adopting new technologies and innovative teaching methods to meet students' learning needs in the digital era (Sourav Saha et al., 2023).

Research Objective

Traditional calculus teaching methods may fail to engage contemporary students. This study examines emerging trends and instructional models in calculus education, employing VOSviewer to quantify and visualize key research directions in response to the growing demand for educational innovation and quality improvement. The research methodology primarily relies on bibliometric analysis, a quantitative and systematic approach that extracts data from a large set of academic publications (Nees Jan van Eck et al., 2010). The study employs the Scopus database, along with VOSviewer software and Citespaces Advanced, to construct knowledge maps, analyze author collaboration, and identify key research topics, thereby identifying influential authors (Wen Lei et al., 2022). Expected outcomes include the identification of development trends, major research topics, and the distribution of author influence, offering insights into the evolution of calculus teaching. Furthermore, the study provides practical recommendations to support

educators, researchers, and policymakers in improving teaching effectiveness and developing training strategies that align with student needs and global education trends (Kai Diethelm et al., 2022).

Research Methodology

This study uses VOSviewer for bibliometric analysis, leveraging data from reputable scientific databases. VOSviewer visualizes bibliometric networks, mapping relationships between publications, authors, and keywords (Nees Jan van Eck et al., 2023). The tool generates research maps, identifying topic clusters and tracking the evolution of calculus teaching methods. It highlights emerging topics and advancements in pedagogy (Ala'a Zuhair Mansour et al., 2021), offering a comprehensive overview of current research and suggesting promising future directions. This analysis lays the groundwork for future innovations in calculus instruction (Qingyan Liu et al., 2025).

Methodology

This study employs bibliometric analysis to investigate emerging trends and models in calculus teaching methods. Bibliometric analysis systematically identifies patterns, trends, and impacts in research by quantifying scientific literature, including publication counts, citations, and methods like citation relationship analysis and co-occurrence analysis (Nees Jan van Eck et al., 2023). The goal is to evaluate and synthesize large volumes of data, offering insights into research trends and patterns (Louis Cohen et al., 2018).

Data Collection

The research data were collected from the leading scientific database, Scopus, due to its broad coverage across various scientific disciplines, which is essential for supporting bibliometric analysis in multidisciplinary research. The study covers articles published from 2000 to 2025. To identify relevant papers, search keywords such as "calculus instruction," "teaching methods in calculus," and

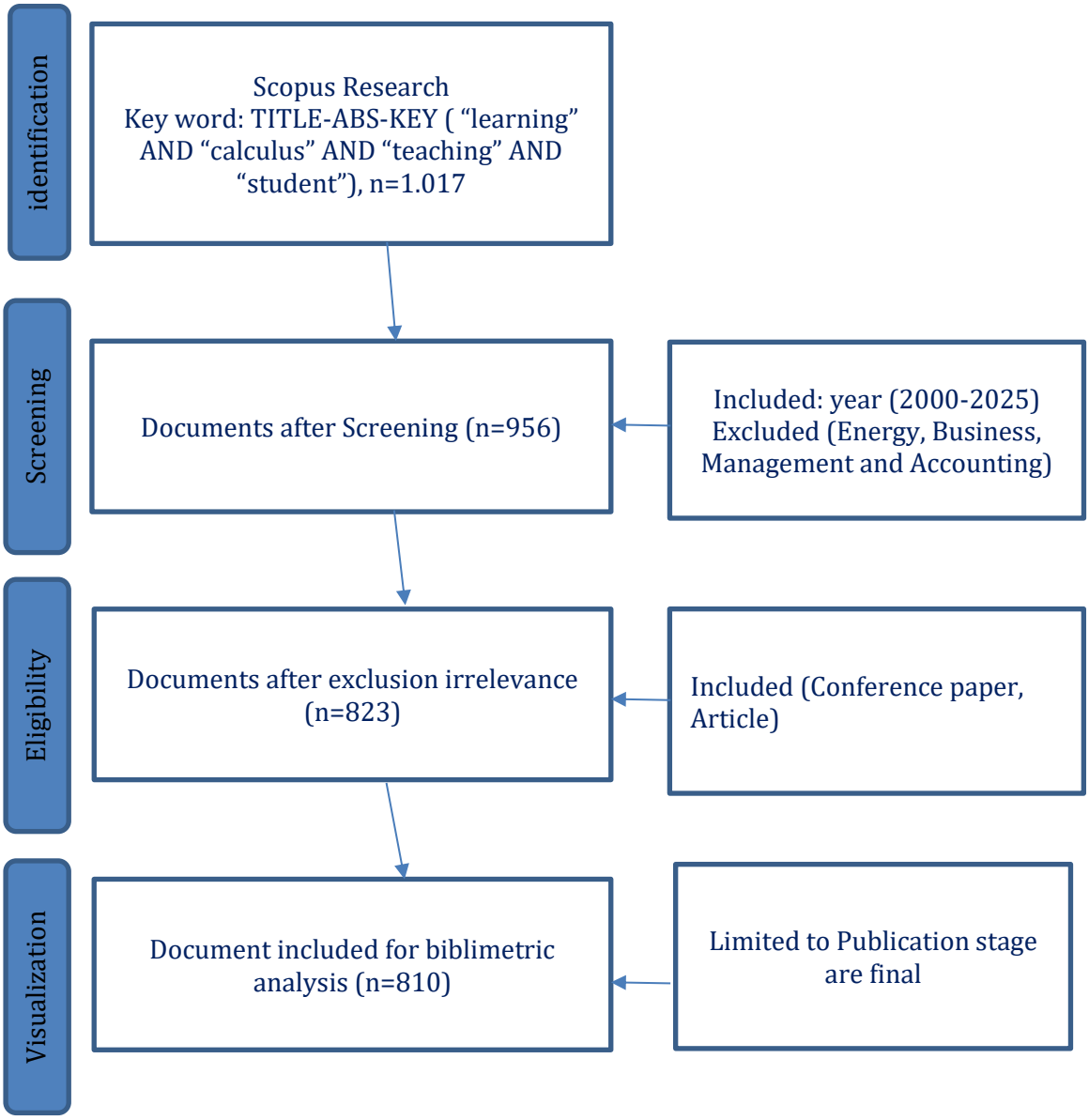
"innovative calculus pedagogy" were used. Analyzing this database provides a comprehensive view of trends and models in calculus teaching methods.

Analysis Tools

VOSviewer is a free software for constructing and visualizing bibliometric maps, offering clear representation of scientific data. Unlike other tools, it emphasizes graphical presentation of large maps, enabling easy exploration and analysis. Features like zooming, scrolling, and searching facilitate detailed examination. VOSviewer generates maps based on co-citation or keyword co-occurrence data, helping researchers identify trends and relationships. It also provides various viewing modes, such as the density view, which highlights research clusters and their interconnections (Nees Jan van Eck et al., 2023).

This software creates networks linking publications, researchers, institutions, countries, keywords, and terms through co-authorship, co-occurrence, citations, or other relationships. The study also employs Citespace Advance to aggregate and process data, visualizing relationships between key research factors. It provides insights into the evolution of teaching methods, helping educators understand progress in teaching innovations (Chaomei Chen, 2014). Citespace Advance identifies influential authors and articles, offering valuable perspectives on improving teaching methods and uncovering emerging trends, particularly in digital transformation and modern learning models (Dan Liu et al., 2022).

Figure 1 – Research procedure for identifying and selecting the documents for bibliometric analysis



In the data analysis process, bibliometric indicators assess research impact and development trends. Citation frequency reflects the influence of articles based on how often they are cited. Publication counts per year reveal the field's development trends, while keyword co-occurrence analysis identifies key research topics. Co-authorship analysis, including co-author, co-citation, and co-occurrence networks, clarifies collaboration patterns and relationships between publications (Abdul Aziz Saefudin et al., 2023). The Scopus database is used to analyze

descriptive content, facilitating exploration of STEM education topics and trends. By leveraging bibliometric methods and tools like VOSviewer and Citespaces Advanced, this study provides insights into emerging trends in calculus teaching, offering valuable perspectives for researchers, educators, and policymakers (Isabel del Arco et al., 2022).

Result and Discussion

Bibliometric analysis of publication output

Yearly Publication, Document Type, and Research Categories

Out of 810 publications related to the topic of calculus in technology and learning identified from the Scopus database between 2000 and 2025, 386 are original research articles (47.7%) and 424 are conference papers (52.3%) (Table 1).

Figure 2 – Distribution of publication from 2000 to 2025

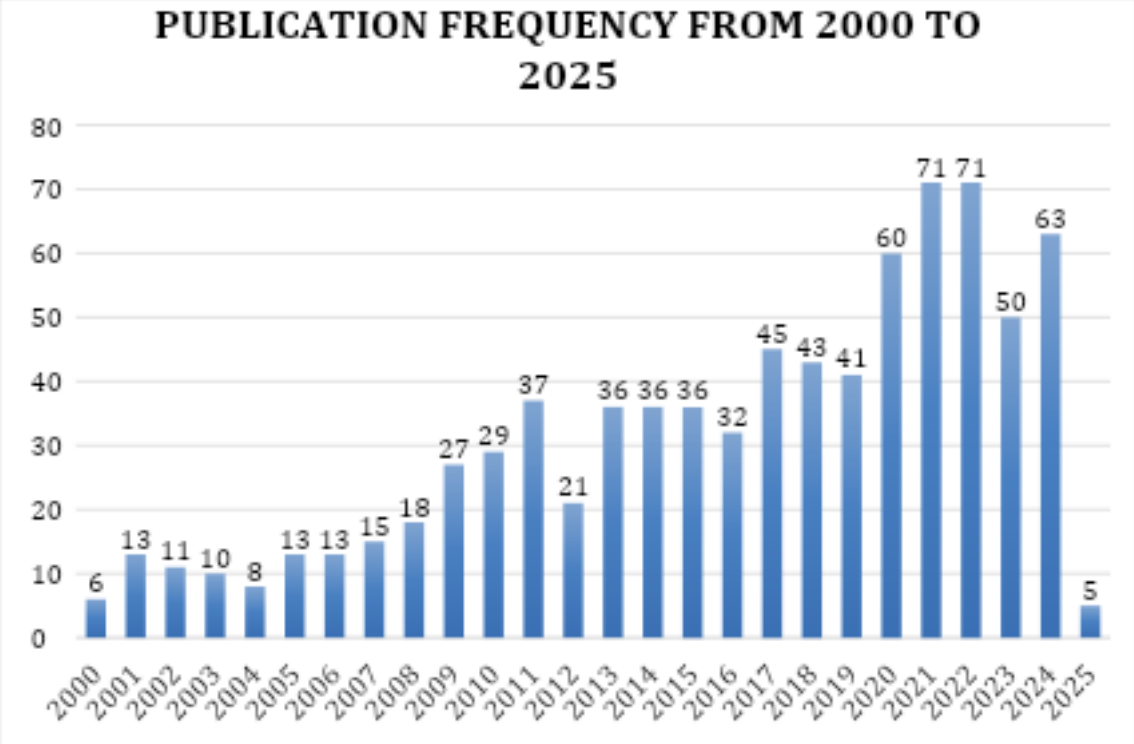
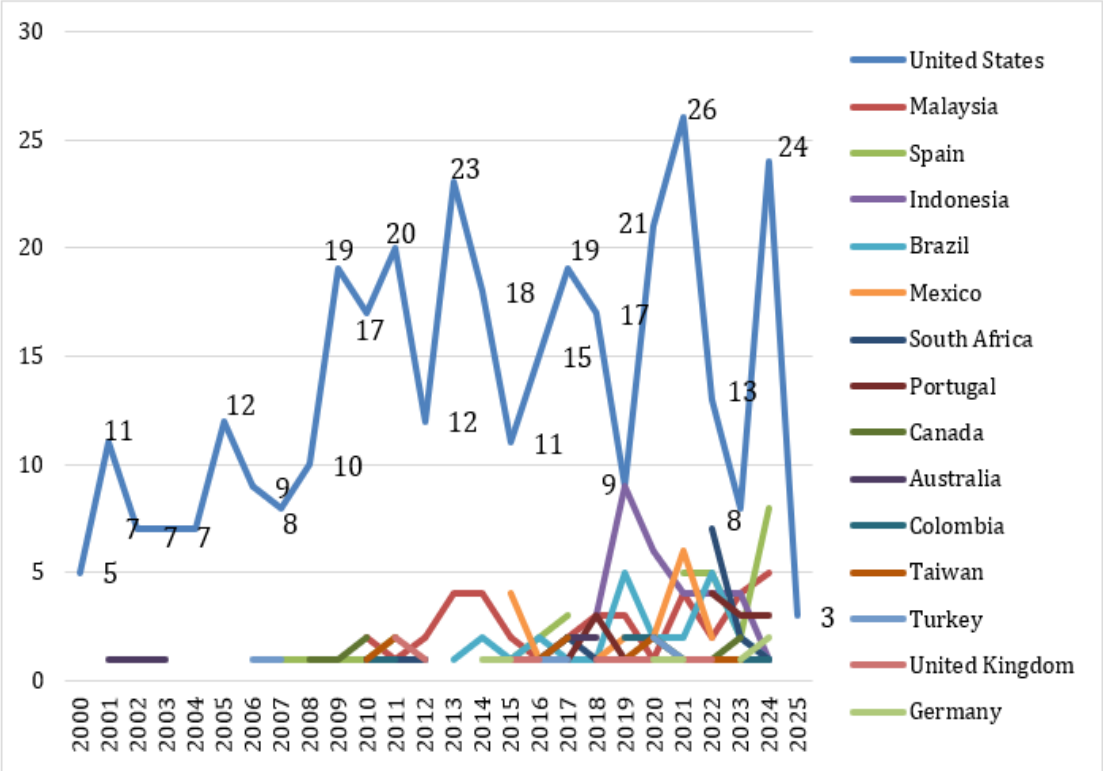


Figure 2 presents the publication frequency of research on calculus teaching methods from 2000 to 2025, indicating a significant growth trend. Starting from a relatively low level in the early 2000s, publication numbers steadily increased from 2009–2010. Notably, the period from 2020–2022 saw a sharp surge, with a peak of 71 publications in two consecutive years, reflecting a concentrated focus on this field within the scientific community. Despite a slight decline in 2023, publication numbers remained high in 2024 and 2025 (60 and 63 publications), illustrating the sustained and growing importance of advanced calculus teaching model research. These data highlight a strong shift, with researchers increasingly focusing on applying calculus to improve technological effectiveness and learning methods, supporting the development of modern education.

Contributions of countries or regions and organizations

Figure 3 shows the distribution of publications on Calculus teaching methods from 2000 to 2025, reflecting the global expansion of research in this field. The United States leads with a significantly higher volume of publications, indicating strong interest and established research tradition. Countries such as Malaysia, Spain, and Indonesia have also seen a notable rise in publications, demonstrating ongoing efforts to improve and diversify teaching methods. The post-2010 growth trend is particularly evident, with a focus on technology-integrated teaching models that enhance student engagement with complex content.

Figure 3 – Distribution of publication from 2000 to 2025



The inclusion of countries such as Mexico, Brazil, South Africa, Portugal, Canada, and Australia at different time points emphasizes the trend of international collaboration, resource sharing, and teaching experience exchange. These shifts reflect the increasing diversity in the research and implementation of Calculus teaching methods, driven by global educational improvement needs. This enhances teaching effectiveness and fosters the development of new teaching models aligned with modern educational reforms.

Figure 4 – Citation of countries in overlay visualization based on total link strength

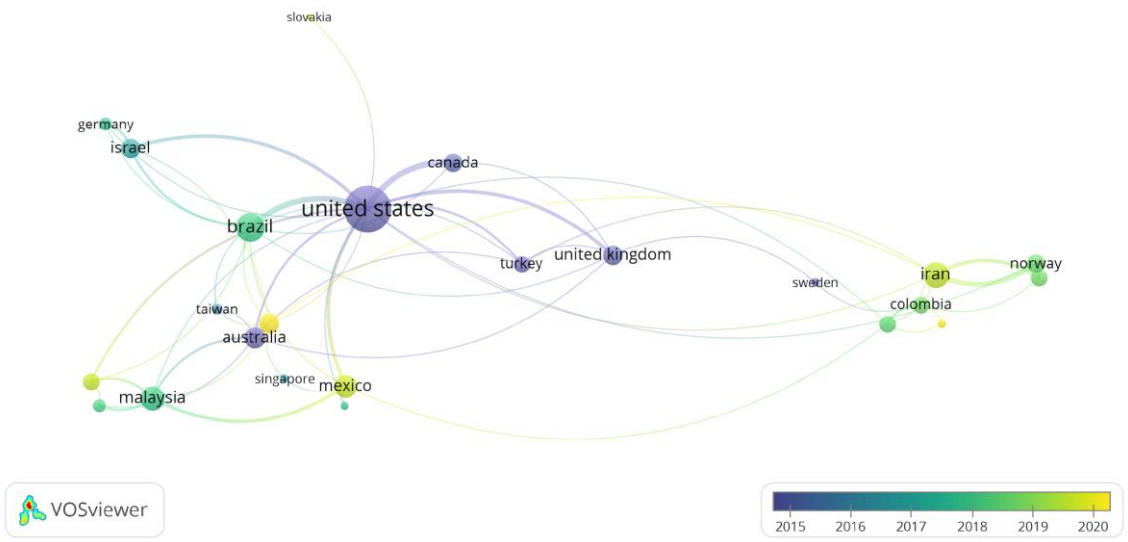


Figure 4 shows the United States leading with 5,726 citations and a total link strength of 33, confirming its pivotal role in shaping and applying advanced teaching methods. Malaysia, with 97 citations and a link strength of 12, demonstrates notable contributions and ongoing efforts to innovate in Calculus teaching. Spain and Indonesia report significant results with 219 and 120 citations, respectively, and link strengths of 6 and 8, reflecting the level of international collaboration and knowledge exchange. Additionally, countries such as Brazil, Mexico, South Africa, Portugal, Canada, and Australia, with citation counts ranging from 59 to 262 and link strengths from 2 to 15, contribute to the diversification of research on Calculus teaching methods. These figures not only highlight the diversity in collaborative networks but also indicate emerging trends in the development of innovative and effective teaching models, driving educational advancements to meet the increasing learning demands in a globalized context.

Table 1 – Publications by document type

Type of Publication	Number of Publications	Percentage of Total Publications (%)
Article	386	52.3
Conference Paper	424	47.7
Total	810	100

Table 1 presents 810 publications on Calculus teaching, including 386 journal articles (52.3%) and 424 conference papers (47.7%). This distribution reflects a balanced focus on academic research and practical application, supporting the development of new pedagogical models. Journal articles provide detailed analysis, while conference papers promote academic exchange and idea dissemination. Consequently, the field of Calculus teaching is positioned to enhance quality and address modern educational demands.

Table 2 – Top 10 Research Areas in Key Publications

Type of Publication	Number of Publications	Percentage of Total Publications (%)
Social Sciences	453	55.93
Engineering	291	35.93
Mathematics	220	27.16
Computer Science	217	26.79
Physics and Astronomy	85	10.49
Psychology	27	3.33
Decision Sciences	21	2.59
Multidisciplinary	13	1.60
Business, Management and Accounting	11	1.36
Materials Science	9	1.11

Table 2 shows the distribution of research areas in publications related to Calculus teaching methods. The most frequently published areas include Social Sciences (55.93%), Engineering (35.93%), and Mathematics (27.16%). The dominance of Social Sciences highlights increasing interest in the social and psychological aspects of teaching Calculus, such as interactive teaching methods, collaborative learning, and online education. Engineering and Mathematics represent substantial shares, reflecting strong growth in the application of technology and mathematical methods in teaching. Although areas like Physics,

Astronomy, Psychology, Decision Science, and Materials Science have lower publication rates, they still indicate significant interest in interdisciplinary teaching models. These figures suggest that Calculus teaching methods are evolving towards greater diversity and integration of new approaches, enhancing teaching and learning effectiveness.

We used VOSviewer software to analyze 810 articles on the co-occurrence of author keywords and research topics related to Calculus teaching. As shown in Figure 5, each node represents a keyword, with node size proportional to its frequency in the studies. The lines connecting nodes reflect co-citation relationships, with thicker lines indicating stronger associations between topics or concepts.

Author keywords, hotspots, and future conduits

Figure 5 – Knowledge network visualization of teaching methods for Calculus based on author keyword co-occurrence (source from VOSviewer software)

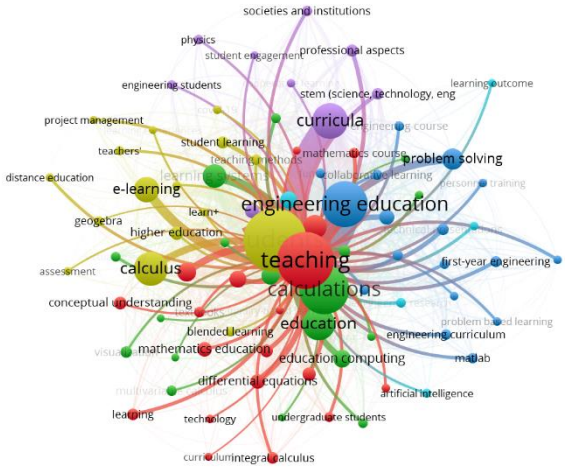


Figure 5 shows the connections between key keywords in Calculus teaching, such as "teaching," "education," "calculations," "engineering education," "problem solving," and "mathematics." These keywords represent major trends in pedagogy, with "teaching" and "education" at the core, linking to concepts like "calculations," "mathematics course," and "problem solving." This reflects the development of teaching methods focused on problem-solving and the application of mathematics

in engineering courses. The strong relationship between "e-learning" and "collaborative learning" indicates a shift toward integrating technology and collaborative learning methods, promoting flexible teaching models to enhance student engagement. Thus, the analysis identifies emerging trends in Calculus teaching, particularly the integration of technology and active learning, which is expected to improve teaching effectiveness in the future (Martene L. Stanberry, 2018).

A detailed analysis of key links in Calculus teaching methods reveals the following: The "calculations" link has 82 connections, with a total link strength of 1487 and 254 occurrences, emphasizing the importance of calculation skills in teaching. The "calculus" link has 62 connections, a link strength of 340, and 131 occurrences, highlighting the focus on analytical methods in teaching. The "teaching" and "students" links each have 83 connections, with total link strengths of 1872 and 2177, and 316 and 380 occurrences respectively, indicating the importance of the teacher-student relationship in pedagogy. The "curriculum" link has 78 connections, a link strength of 991, and 145 occurrences, underscoring the necessity of effective curriculum design. The "problem solving" link has 56 connections, a link strength of 334, and 58 occurrences, reflecting the trend toward incorporating real-world problems in teaching. The "e-learning" link has 65 connections, a link strength of 390, and 80 occurrences, highlighting the role of technology in modern teaching. Finally, the "education" and "educational computing" links have 125 and 43 occurrences, with total link strengths of 760 and 265, respectively, reflecting the growing importance of technology and modern educational methods in Calculus instruction.

Figure 6 – Knowledge density visualization of teaching methods for Calculus based on author keyword co-occurrence (source from VOSviewer software)

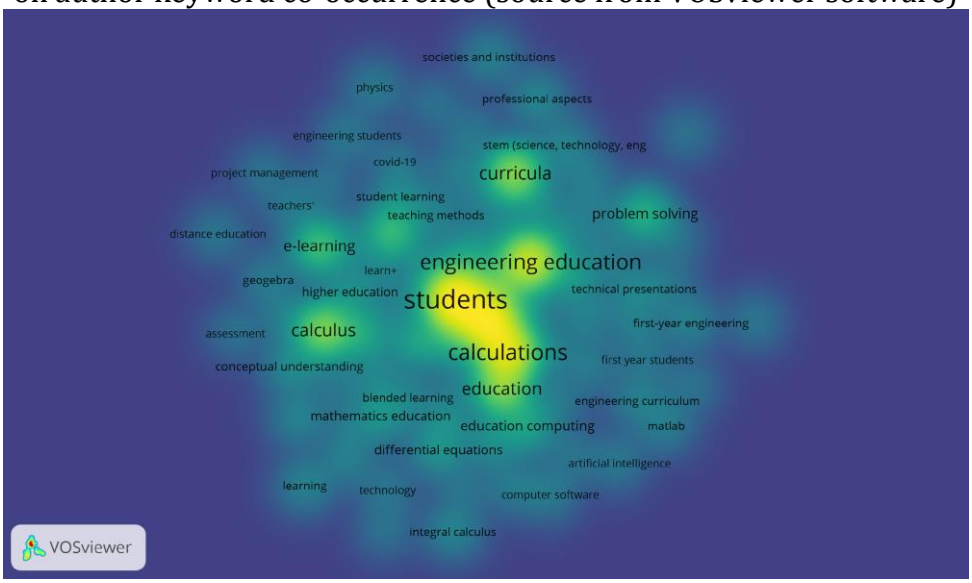


Figure 6 illustrates the knowledge density map for teaching methods in Calculus, based on the co-occurrence of author keywords. The keywords "students" and "calculations" are predominant, indicating a focus on student needs and calculation skills in Calculus instruction. Other prominent keywords, such as "engineering education," "curricula," and "problem solving," reflect the trend towards applying interdisciplinary teaching methods, especially in engineering education. Connections like "e-learning" and "education computing" demonstrate the strong shift towards the integration of technology in Calculus teaching.

Figure 7 – The co-citation network of author (source from VOSviewer software)

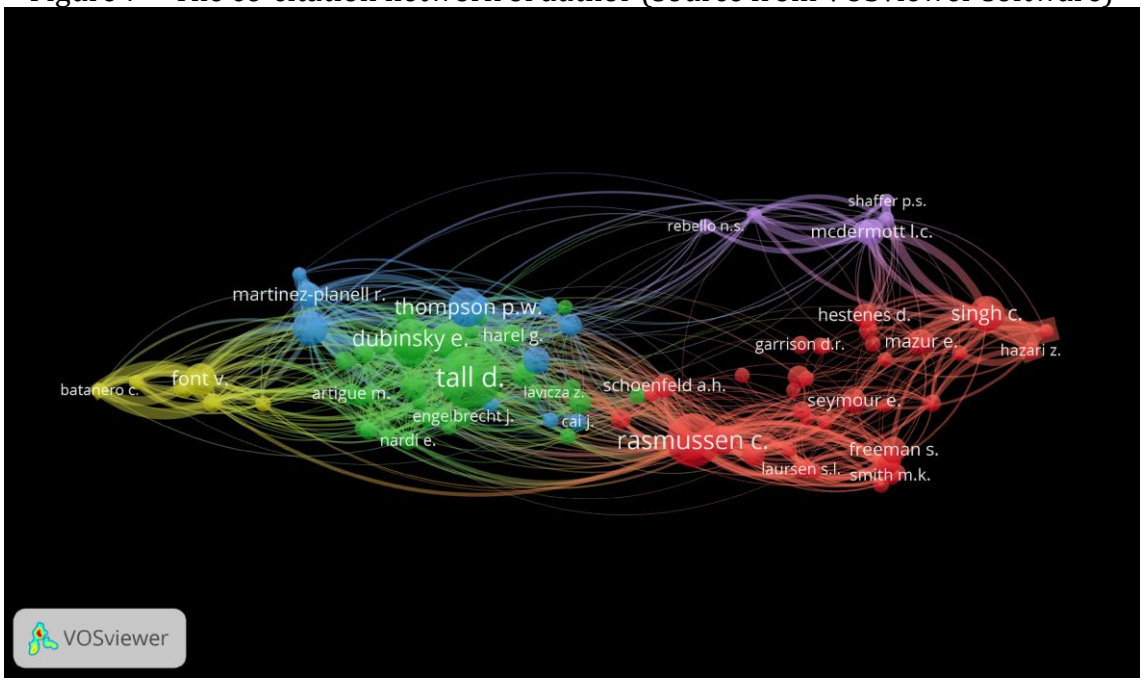


Figure 7 presents the co-citation network of authors, illustrating relationships between studies on Calculus teaching methods. Distinct color clusters represent groups of authors with strong thematic and content connections. For example, the green cluster includes authors like Tall D., Dubinsky E., and Harel H., who made significant contributions to the development of Calculus teaching through theories of concept formation and student understanding. The red cluster, featuring authors such as Rasmussen C. and Schoenfeld A.H., emphasizes problem-solving models and assessment methods in Calculus instruction. Other clusters, such as the purple and blue groups, are linked to research on technology and distance learning, reflecting the growing integration of ICT and online learning in Calculus teaching. This co-citation network offers insights into the development and emerging trends in Calculus pedagogy, particularly in the integration of theory, technology, and collaborative learning approaches.

Figure 8 – The co-citation network of sources (source from VOSviewer software)

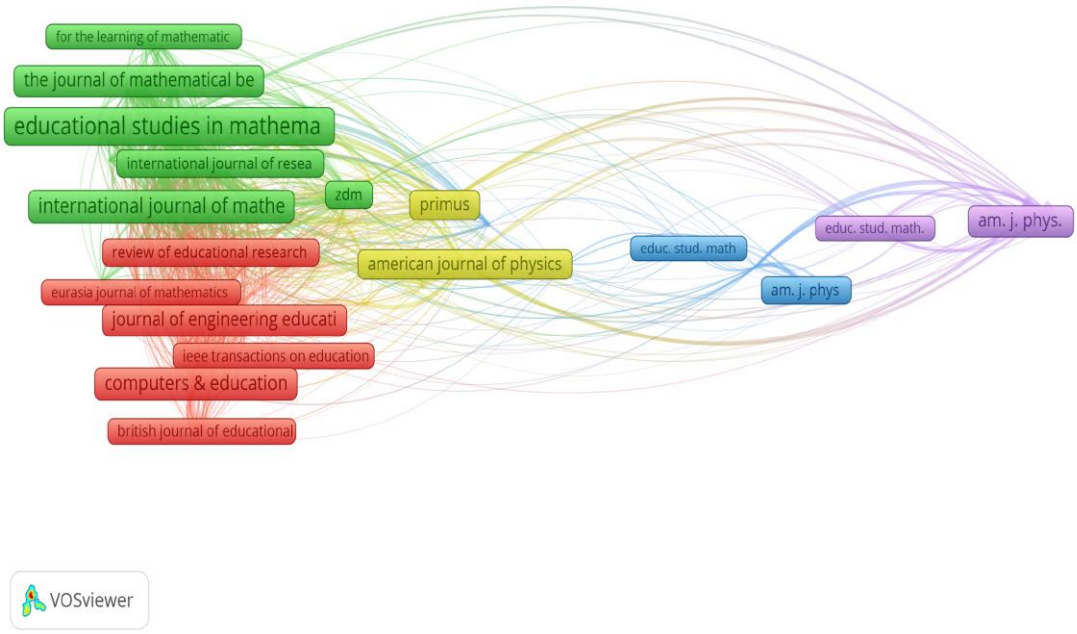


Figure 8 shows the citation network among sources, highlighting the connections and interactions between research journals in calculus teaching. Color-coded groups represent journals with strong citation relationships, aiding the analysis of links between research fields. The red and green groups, featuring journals like *Educational Studies in Mathematics*, *International Journal of Mathematical Education*, and *The Journal of Mathematical Behavior*, emphasize the development of teaching theories, particularly educational methods and subject understanding. Journals such as *Computers & Education*, *Journal of Engineering Education*, and *IEEE Transactions on Education* are linked to the yellow and orange groups, indicating a growing use of technology in teaching calculus, especially through software tools and online learning. This trend reflects the integration of technology to improve classroom interaction and learning outcomes. Additionally, the *American Journal of Physics* and *Review of Educational Research* in the purple and blue groups indicate the connection between calculus teaching and natural sciences, especially physics, demonstrating the links between STEM subjects in teaching

mathematics and calculus. Overall, the image illustrates the diverse development of calculus teaching models, particularly the combination of theory, technology, and related scientific fields.

Figure 9 – The Evolution of Research Trends in Engineering Education and Teaching Methods (source from CiteSpace Advance software)

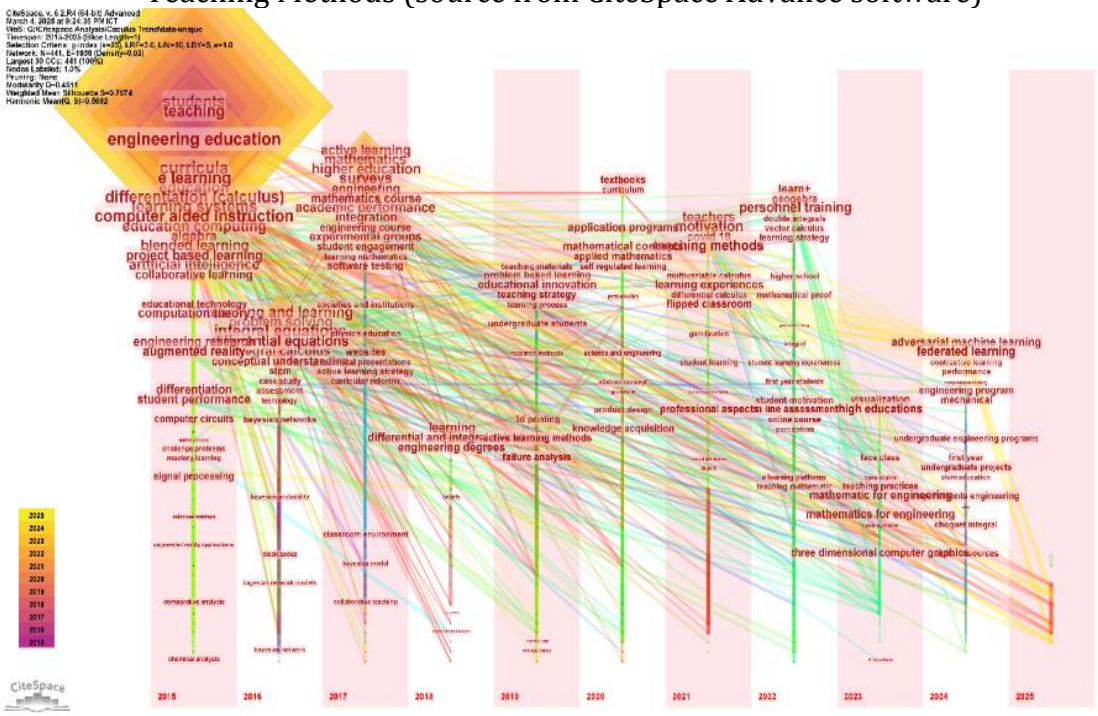


Figure 9 shows the evolution of research trends in engineering education and calculus teaching methods, analyzed using CiteSpace Advance software. Each color in the figure represents a research phase from 2015 to 2025, with the links between keywords reflecting the development of teaching models and emerging research trends.

The keywords "engineering education" and "teaching" are prominent, indicating a focus on teaching in engineering, particularly in calculus education. Related topics such as "differentiation (calculus)", "computer-assisted instruction", and "collaborative learning" highlight a shift from traditional methods to modern approaches using technology and collaborative learning. The link between "mathematics education" and "application programming" reflects the growing connection between mathematics and practical applications, especially in technical

and engineering programs. Additionally, keywords like "federated learning", "advanced machine learning", and "personal training" point to the increasing application of machine learning and personalized learning methods in calculus education. This reflects the integration of modern technology into teaching methods to provide flexible, effective learning experiences tailored to students' needs. The temporal distribution of keywords shows that calculus teaching models are evolving, particularly in the application of technology and collaborative learning methods, fostering sustainable development and innovation in the field.

Figure 9 highlights the connecting lines between keywords, representing the relationships between research topics over time. The lines indicate the degree of connection and the ongoing development of trends in calculus education. Thicker lines represent stronger co-citation, indicating frequent joint study and application of concepts in research. Links between "engineering education," "differentiation (calculus)," "teaching methods," and "learning outcomes" show the integration of calculus teaching with engineering education principles and effective learning. The strong connection between "mathematics education" and "technology" reflects the trend of incorporating technology into new teaching methods. The image also illustrates the shift from traditional to flexible, personalized learning models, with the rise of "federated learning" and "personal training" in recent years. This points to the growing dominance of technology, collaborative learning, and personalized methods in calculus education to improve effectiveness and student engagement.

Figure 10 – The Co-occurrence Network of Keywords in Calculus Teaching Research (source from CiteSpace Advance software)

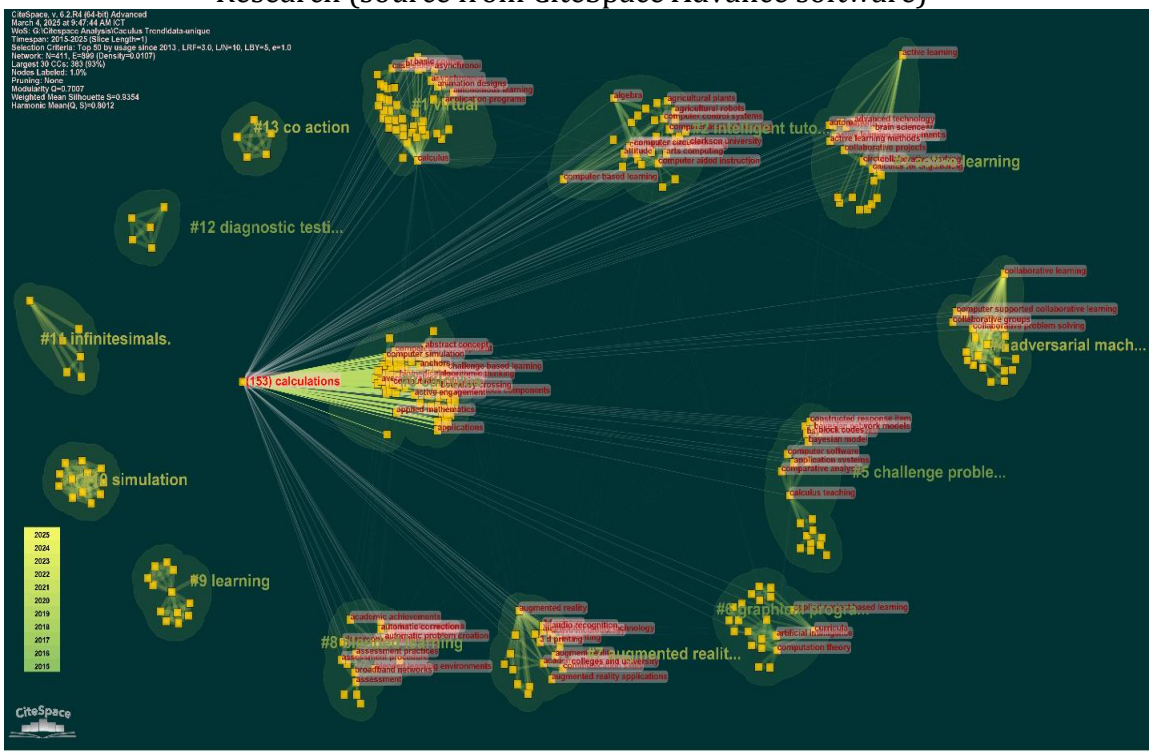


Figure 10 illustrates the co-occurrence network of keywords in calculus teaching research, analyzed using CiteSpace Advance. It provides deeper insights into the distribution and evolution of keywords over time. Keywords are grouped into distinct clusters, revealing the emergence of key research trends in calculus education. The keyword "calculations" is central, with strong connections to terms like "infinitemals," "simulation," and "diagnostic tests," reflecting the importance of computational methods and diagnostic assessments in teaching calculus. Clusters such as "adversarial machine learning" and "augmented reality" highlight the shift toward applying modern technologies in this field, particularly through the integration of machine learning and virtual reality. The temporal evolution is shown by the shift from clusters related to "learning" and "teaching" in recent years to more complex technology-related topics like "augmented reality" and "adversarial learning." This indicates progress in calculus education, combining traditional methods with modern technology to enhance learning effectiveness and create more innovative learning experiences for students.

Table 3 – Top 10 highest cited references

Rank	Titles	Journals	IF[a] (2023)	First authors	Total citations, n
1	Peer Instruction: Ten years of experience and results (Catherine H. Crouch et al., 2001)	American Association of Physics Teachers	0.9	Catherine H. Crouch	1757
2	Individual differences in non-verbal number acuity correlate with maths achievement (Justin Halberda et al., 2008)	Nature	50.5	Justin Halberda	1157
3	Predicting student academic performance in an engineering dynamics course: A comparison of four types of predictive mathematical models (Shaobo Huang et al., 2013)	Computers & Education	4.1	Shaobo Huang	310
4	Exploring the relationship between self-efficacy and retention in introductory physics (Vashti Sawtelle et al., 2012)	Journal of Research in Science Teaching	3.6	Vashti Sawtelle	181
5	Comparison of student performance using web and paper-based homework in college-level physics (Scott W. Bonham et al., 2003)	Journal of Research in Science Teaching	3.6	Scott W. Bonham.	128
6	Flipping Calculus (Jean McGivney-Burelle et al., 2013)	Problems, Resources, and Issues in Mathematics Undergraduate Studies,	0.7	Jean McGivney-Burelle	109
7	Gendered patterns in the construction of physics identity from motivational factors (Z. Yasemin Kalender et al., 2019)	Physical Review Physics Education Research	2.8	Z. Yasemin Kalender	100
8	Applications geogebra into teaching some topics of mathematics at the college level (Ljubica Dikovic, 2009)	Computer Science and Information Systems	1.2	Ljubica Dikovic	86
9	Dynamic mathematics with GeoGebra (Markus Hohenwarter et al., 2007)	Journal of Online Mathematics and its Applications		Markus Hohenwarter	82
10	Improving first-year engineering education (N.A. Pendergrass et al., 2001)	Journal of Engineering Education	3.146	N.A. Pendergrass	73

Table 3 highlights key studies in calculus teaching methods, particularly those focused on improving teaching strategies and applying technology. The study *"Peer Instruction: Ten years of experience and results"* by Catherine H. Crouch (1757 citations) leads, emphasizing active teaching methods that encourage student

participation and enhance learning outcomes. *Jean McGivney-Burelle's study "Flipping Calculus"* (109 citations) reflects the application of the flipped classroom model, where students learn theory outside class and complete exercises in class, showing the trend of using technology in calculus teaching. Other studies, such as *"Dynamic Mathematics with GeoGebra"* (Markus Hohenwarter) and *"Applications of GeoGebra in Teaching Some Topics of Mathematics"* (Ljubica Dikovic), highlight the increasing use of GeoGebra software in calculus teaching, aiding students in visualizing complex mathematical concepts. The integration of traditional methods with digital technology, as seen in studies like *"Predicting Student Academic Performance"* and *"Gendered Patterns in Physics Identity,"* shows the trend of incorporating technology and personalized learning methods to enhance teaching effectiveness. These studies indicate a significant shift in calculus education, combining theory with practical applications.

Explanation of Result

Analysis of the development trends in calculus teaching methods shows significant growth in research from 2000 to 2025, with a notable increase during the 2020-2022 period. In terms of research distribution by country and region, the United States leads in publications, while countries like Malaysia, Spain, and Indonesia also report an increase in research in this area. At the same time, international collaboration in calculus teaching has strengthened. Key research areas include Social Sciences, Engineering, and Mathematics, with Social Sciences dominating, reflecting growing interest in the social and psychological factors in calculus education.

The prominent research topics in calculus teaching, based on keyword analysis, include critical elements such as computational skills, the relationship between teaching and learning, effective curriculum design, and the application of real-world problems and technology. The link to "computation" highlights the importance of this skill in teaching, particularly when connected with factors like "teaching" and "students," reflecting the strong relationship between instructors

and learners in enhancing learning outcomes. Additionally, the necessity of effective curriculum design is emphasized through the "curriculum" link, guiding appropriate learning methods. The trend of applying real-world problems in teaching, through the link "problem solving," demonstrates the shift from theory to practical application. Finally, the use of technology, especially "e-learning," underscores the growing role of technology in improving and innovating modern teaching methods.

The analysis of the co-citation network of authors and sources clarifies the development and emerging trends in calculus teaching, particularly in the context of combining theory, technology, and collaborative learning methods (Roberto Torres et al., 2024). The evolution of research trends is highlighted through the use of CiteSpace Advance software, demonstrating the shift from traditional teaching methods to modern approaches utilizing technology and collaborative learning (Zhenyu Chen et al., 2024). The synthesis of the most-cited studies should be analyzed to clarify effective teaching methods and the application of technology in calculus education, reflecting the significant contributions and long-lasting impact of these studies on the field's development.

Implications for Education

The innovation of teaching methods in calculus has shifted significantly from traditional approaches to more modern methods that integrate technology and promote collaborative learning. This requires educators to continuously update and innovate their teaching methods to meet the diverse learning needs of students (Bendebal Malika et al., 2024). The analysis results also highlight the increasingly important role of technology in calculus education, particularly e-learning, educational computing, and tools like GeoGebra. Educators should leverage digital tools and resources to visualize abstract concepts, provide immediate feedback, and facilitate personalized learning. Furthermore, the research shows the trend of applying real-world problems in calculus teaching, encouraging educators to design learning activities focused on problem-solving and the application of mathematics in real-life situations, helping students not only master knowledge but also develop creative thinking skills.

The analysis underscores the need for effective curriculum design, urging policymakers and educators to collaborate on programs aligned with student needs and global educational trends. The study also highlights a rise in international collaboration in Calculus instruction, prompting educators and researchers to share resources and expertise to develop new teaching models. A notable trend is the growing interest in integrated STEAM (Science, Technology, Engineering, Arts, and Mathematics) approaches, which enhance learning outcomes and foster essential student skills (Roberto Torres et al., 2024). However, the research reveals a decline in scholarly focus on mathematical competencies, emphasizing the ongoing need to refine instructional methods to strengthen students' mathematical abilities.

Practical Implications

This study highlights the role of technological advancements, particularly e-learning, simulation software, and online tools like GeoGebra, in enhancing students' understanding of abstract concepts and delivering personalized, rapid feedback (Sirak Tsegaye Yimer, 2022). Furthermore, it emphasizes the need for effective curriculum design tailored to students' needs and global educational trends, while addressing the increasing trend of international collaboration. This collaboration promotes experience-sharing and the development of new teaching models, particularly STEAM-based approaches, which equip students with essential skills for studying Calculus (Ana Breda et al., 2023).

Comparison with Prior Studies

This study validates and builds upon prior findings on the significance of integrating technology into mathematics education. It further contributes to existing research on active teaching methods, including collaborative learning and problem-based learning. Utilizing tools such as VOSviewer and CiteSpace Advance, the study offers a comprehensive overview of emerging trends and models in Calculus instruction, emphasizing the fusion of technology with modern learning methodologies.

Limitations

Research data was collected solely from the Scopus database and English-language articles, potentially overlooking important studies in other languages. The research period focused on articles from 2000 to 2025; future studies should expand the time frame to identify long-term trends.

Future Directions

Future studies should employ qualitative methods to deeply investigate the experiences and perspectives of students and teachers on Calculus teaching methods. Comparative research assessing the effectiveness of different teaching approaches using objective metrics such as exam scores and learning outcomes is also a crucial direction (Uluhan Kurt et al., 2021). Moreover, longitudinal studies tracking students over extended periods can help determine the long-term impacts of these methods. Additional research is essential to refine teaching strategies, enhance mathematical proficiency, and integrate emerging technologies like augmented reality (AR), virtual reality (VR), and machine learning into Calculus instruction.

Conclusion

Summary of Main Insights

The study identifies the trend of adopting modern methods, integrating technology, collaborative learning, and problem-solving to address students' learning needs. Technology, especially e-learning, simulation software, and online tools, plays a critical role in enhancing teaching effectiveness and fostering an interactive learning environment.

Contribution to the Field

Studies emphasize the role of international collaboration, experience sharing, and the development of learning communities in advancing innovative Calculus teaching models. Additionally, the adoption of integrated STEAM (Science,

Technology, Engineering, Arts, and Mathematics) teaching models has become a dominant trend in Calculus education.

Closing Remark

Further research is required to refine teaching methods and enhance students' mathematical proficiency, especially amid declining mathematical capabilities. Continuous advancements in teaching strategies are essential to meet the increasing demands of Calculus education and research.

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