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GLOBAL ACADEMIC EXCELLENCE

STEM EDUCATION RESEARCH: GLOBAL PATTERNS AND TRENDS FROM A BIBLIOMETRIC ANALYSIS

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Abstract:

STEM education has gained worldwide attention as countries work to equip students with the skills needed for fast-changing technological, economic, and social environments. To better understand how research in this area has evolved, this study presents a bibliometric review based on 420 documents retrieved from the Scopus database. The study aims to (1) examine publication growth and distribution trends, (2) identify the most influential authors, institutions, countries, and sources, and (3) map the intellectual and collaborative structures shaping STEM education research. To achieve these objectives, Scopus Analyzer was employed to generate descriptive performance indicators, while VOSviewer was used to visualize co-authorship networks, keyword co-occurrence clusters, and citation linkages. The findings show a consistent upward trajectory in STEM education publications, with notable growth in the past ten years. The United States, China, Australia, and the United Kingdom emerged as leading contributors, supported by strong institutional outputs and international collaboration networks. Keyword co-occurrence mapping revealed dominant research themes such as STEM integration, engineering education, computational thinking, robotics, inquiry-based learning, gender equity, and technology-enhanced instruction. Emerging topics, including virtual reality, artificial intelligence in education, and inclusive STEM pedagogies, also appear with increasing frequency, indicating expanding research frontiers. Overall, the study gives a clear overview of global STEM education research by identifying major contributors, key themes, and collaboration patterns, offering useful insights for educators, researchers, and policymakers to guide future work in the field.

Keywords:

STEM Education, Bibliometric Analysis, Scopus Database, VOSviewer, Research Trends

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Introduction

Innovation in Science, Technology, Engineering, and Mathematics (STEM) education is paramount for preparing a capable, adaptable, and future-ready workforce. As rapidly evolving technological domains reshape economies and societies, STEM education must continuously innovate to equip learners with relevant competencies and foster their ability to navigate complex challenges. Emerging technologies such as artificial intelligence (AI), robotics, open-source hardware, virtual reality (VR), gamification, and data analytics have begun to transform traditional pedagogical practices, creating new opportunities for student engagement, personalized learning, and interdisciplinary integration (Fruett et al., 2024; Huang et al., 2025; Boltsi et al., 2024).

Yet, innovation in STEM education is incomplete without meaningful inclusivity. Despite growing recognition of STEM fields' importance, significant disparities persist in participation and success among women, ethnic minorities, disabled individuals, and other marginalized groups. Barriers such as stereotypes, lack of role models, systemic biases, and accessibility challenges hinder equitable access and progression in STEM disciplines (Costa et al., 2024; Stone-Sabali et al., 2024; Das & Pal, 2024). Addressing these inequities by embedding diversity, equity, inclusion, and justice (DEIJ) principles into the very fabric of STEM education is essential not only for social justice but also for enriching STEM fields with diverse perspectives that drive creativity and innovation (Diaz & Wankowicz, 2024).

Technological innovations are powerful enablers of inclusive pedagogy. For example, adaptive learning systems powered by AI and high-performance computing can tailor curricula to diverse learner profiles, accommodating varied skill sets and learning styles while providing real-time personalized support to enhance engagement and retention (Huang et al., 2025). Similarly, robotics platforms, including assistive robotics, offer hands-on experiential learning opportunities that not only improve STEM skills but also support students with disabilities in becoming active participants in STEM education (Escudeiro et al., 2024). Virtual and augmented reality technologies foster immersive and accessible learning environments, breaking physical and cognitive barriers to participation and providing novel modalities to engage learners of different backgrounds and abilities (Jin et al., 2024; Mystakidis et al., 2024).

Emerging pedagogical strategies such as project-based learning, maker culture, and gamification offer promising avenues to motivate students and foster creativity, collaboration, and critical thinking skills essential for STEM careers. These methodologies align well with the integration of digital tools and open hardware/software platforms exemplified by systems like BitDogLab, which promote low-cost, adaptable, and community-driven STEM educational experiences across diverse age groups (Fruett et al., 2024; Zhao et al., 2022); Tabarés & Boni, 2023). Furthermore, culturally responsive teaching approaches that incorporate local contexts, narratives, and identity-affirming practices are critical to sustaining interest and participation among underrepresented students in STEM (Akumbu, 2024; Jin et al., 2025).

Research Question

1. What are the research trends in STEM education according to the year of publication?
   Relevence: This aligns directly with the word *"patterns"* in the title. By analyzing yearly publication trends, the study identifies how research output in STEM education

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has grown, stagnated, or shifted globally. It reflects temporal patterns and helps readers understand the evolution of the field.

2. Who and how much has been published in the area with regard to the authors, their affiliated organisations and countries?
   Relevence: This addresses the "global" dimension of the title. Mapping the contributions of authors, institutions, and countries uncovers geographical distribution and productivity patterns. It shows which regions and institutions are leading or emerging in STEM education research, reinforcing the study's global scope.

3. What are co-occurrence, co-authorship, and co-citation between countries' collaboration?
   Relevence: This connects to the "bibliometric analysis" part of the title. Examining co-occurrence (keywords), co-authorship (collaboration networks), and co-citation (intellectual linkages) reveals structural patterns in the STEM education knowledge domain. It highlights not only collaboration intensity but also intellectual connections shaping the field globally.

Methodology

Bibliometrics refers to the collection, management, and analysis of bibliographic data derived from scientific publications (Verbeek et al., 2002). In addition to basic descriptive statistics, such as publication year, contributing journals, and classification of main authors (Wu & Wu, 2017), bibliometrics also employs more advanced techniques, including document co-citation analysis. Conducting an effective bibliometric review requires an iterative process involving the selection of appropriate keywords, systematic literature searches, and refined analyses to build a reliable bibliography and achieve valid results (Fahimnia et al., 2015). Furthermore, journals listed in the Clarivate Analytics Journal Citation Reports (JCR) with an assigned impact factor are generally regarded as high-quality outlets (Meier, 2011).

Accordingly, this study focused on top-tier publications, as they provide deeper insights into the theoretical perspectives underpinning the evolution of the research domain. To achieve this, data collection was carried out using Thomson ISI Web of Science (WoS), which has been widely recognized for its reliability (Di Stefano et al., 2010; Tan et al., 2014). To ensure the inclusion of only high-quality research, the analysis was restricted to peer-reviewed journal articles, excluding books and conference proceedings (Liu et al., 2015). Compared to Elsevier's Scopus, which primarily covers recent publications, WoS provides strong and consistent coverage dating back to 1990 (Aghaei Chadegani et al., 2013). For the present study, articles indexed in the Social Sciences Citation Index (SSCI), Science Citation Index Expanded (SCIE), and Arts and Humanities Citation Index (A&HCI) from 2010 to December 2020 were selected for analysis. The Clarivate Analytics WoS Core Collection, recognized for its extensive citation and bibliographic coverage in the social sciences and humanities, was therefore adopted as the primary database for retrieving articles (Aghaei Chadegani et al., 2013; Olijnyk, 2015).

Data Search Strategy

The study employed a screening sequence to determine the search terms for article retrieval. The study was initiated by querying the Scopus database (Table 1 and Table 2), assembling 420 articles.

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Table 1
The Search String

Scopus	TITLE-ABS-KEY (science AND technology AND engineering AND mathematic AND in AND education) AND PUBYEAR > 2009 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE , "English"))

Table 2
The Selection Criterion in Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2009 - 2025	< 2009
Literature type	Journal (Article)	Conference, Book, Review

Data Analysis

Datasets containing publication year, title, author names, journal, citations, and keywords were extracted in PlainText format from the WoS database, covering the period from 2009 to June 2025. These datasets were analyzed using VOSviewer software (version 1.6.15), which was applied to generate bibliometric maps through its clustering and mapping techniques. VOSviewer serves as an alternative to the Multidimensional Scaling (MDS) approach (Van Eck & Waltman, 2010). Similar to MDS, its purpose is to represent items in a low-dimensional space such that the distance between items reflects their relatedness or similarity (Appio et al., 2014). However, unlike MDS, which relies on similarity measures such as Jaccard indices and cosine values, VOS employs a more appropriate normalization technique for co-occurrence frequencies, namely the association strength (ASij) (Van Eck & Waltman, 2007). The association strength is calculated as:

ASij ¼ Cij
Wiwj

which is "proportional to the ratio between on the one hand the observed number of cooccurrences of i and j and on the other hand the expected number of co-occurrences of i and j under the assumption that co-occurrences of i and j are statistically independent" (Van Eck and Waltman, 2010, p. 531). Hence, with help of this index, VOSviewer places items in the form of a map after reducing the weighted sum of the squared distances between all item pairs. According to Appio et al. (2016), the LinLog/modularity normalization was implemented. Furthermore, by applying visualisation techniques through VOSviewer to the data set, patterns built on mathematical relationships were uncovered and analyses such as keyword co-occurrence, citation analysis and co-citation analysis were performed.

Using this index, VOSviewer positions items on a map by minimizing the weighted sum of squared distances between item pairs. As noted by (Appio et al., 2016), the LinLog/modularity normalization was applied. Through the visualization techniques available in VOSviewer, mathematical relationships within the dataset were revealed, enabling analyses such as keyword co-occurrence, citation analysis, and co-citation analysis. Keyword co-occurrence analysis, in particular, allows for the exploration of research area development over time (Zhao, 2017) and is effective in identifying emerging and popular topics across various fields (Li et

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al., 2016). Citation analysis, on the other hand, is valuable for identifying key research issues, trends, and methodologies, while also highlighting the historical significance of a discipline's central themes (Allahverdiyev & Yucesoy, 2017). Document co-citation analysis is another widely applied bibliometric method (Appio et al., 2016; Fahimnia et al., 2015; Liu et al., 2015), producing results in the form of maps based on network theory to reveal the structural relationships within the data (Liu et al., 2015).

Findings

What Are The Research Trends In STEM Education According To The Year Of Publication?

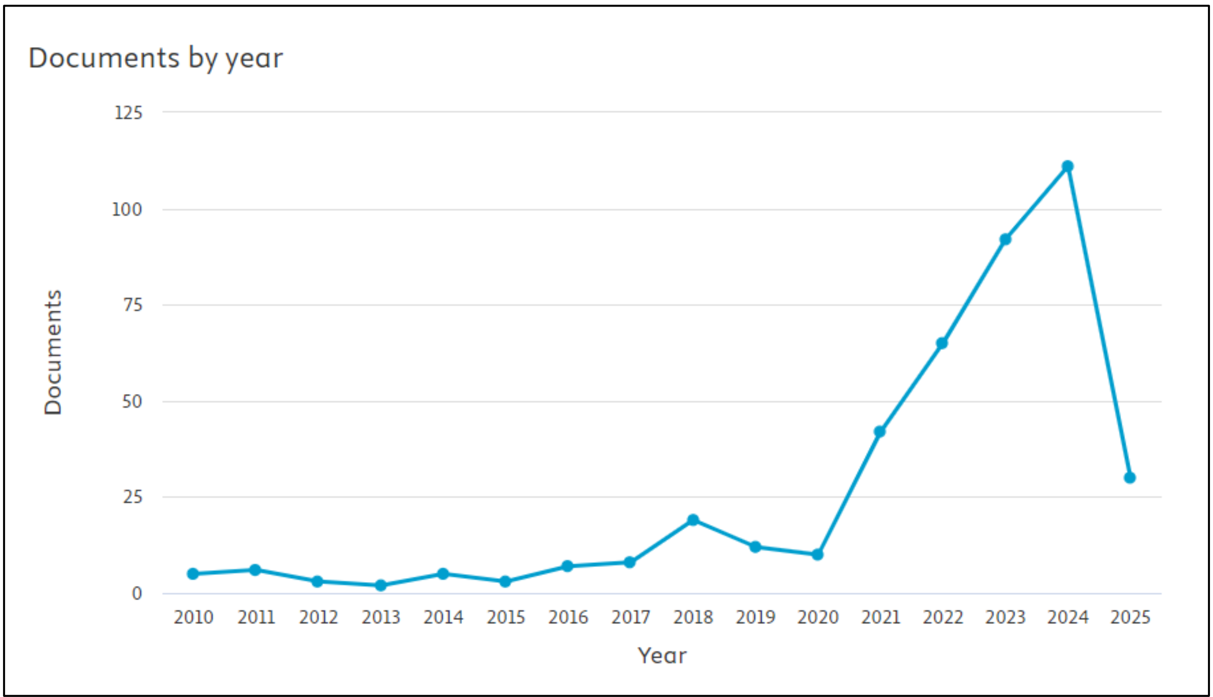

Figure 1: Trend of Research in STEM Education Published By Year.

Figure 1 shows the number of STEM education publications published each year between 2010 and 2025. The publication trend from 2010 to 2025 shows a steady growth in scholarly output with a significant acceleration beginning in 2020. From 2010 to 2019, the numbers fluctuated at a relatively low level, ranging from 2 to 19 publications annually, indicating a period of gradual and modest growth. A notable turning point occurred in 2020, with the output rising sharply from 10 publications in 2020 to 42 in 2021 and then nearly doubling again to 65 in 2022. This upward trajectory continued into 2023 with 92 publications and peaked in 2024 with 111 publications, marking the highest productivity within the observed period.

In 2025, however, the number of publications dropped to 30, a decline that may be due to incomplete data for the year or a genuine slowdown in research dissemination. Overall, the trend suggests that the field has experienced rapid expansion in the early 2020s, possibly driven by increased research funding, global attention, or collaborative initiatives. Despite the dip in 2025, the general pattern points to growing interest and stronger engagement in the research

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area compared to the pre-2020 period, which may indicate a maturing and consolidating research community.

Who And How Much Has Been Published In The Area With Regard To The Authors, Their Affiliated Organisations And Countries?

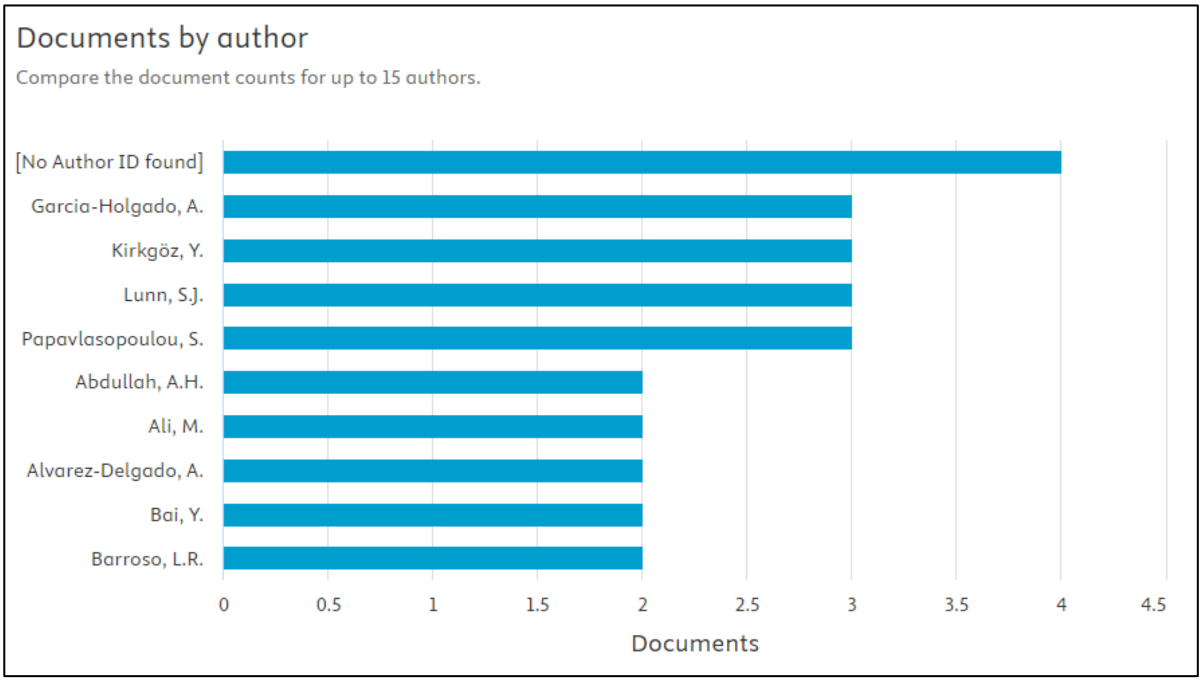

Figure 2: Top Contributing Authors And Their Number Of Publications.

Figure 2 highlights the individual contributions of researchers to the publication set. The category [No Author ID found] ranks the highest with 4 documents, reflecting cases where author identifiers were missing or not properly indexed in the database. Among identified authors, several stand out with three publications each, including Garcia-Holgado, A., Kirkgöz, Y., Lunn, S.J., and Papavlasopoulou, S.. Their repeated appearances suggest consistent engagement in this research domain and likely influence in shaping its direction through multiple contributions. A second tier of contributors includes Abdullah, A.H., Ali, M., Alvarez-Delgado, A., Bai, Y., and Barroso, L.R., each with two publications. While fewer in number compared to the leading group, their presence indicates meaningful involvement and growing participation in the field. Collectively, the distribution suggests that while a handful of authors are contributing regularly, the overall publication landscape is relatively dispersed, without a single dominating figure, pointing toward a collaborative and diverse authorship pattern.

Figure 3 indicates that the United States is the most prolific contributor to STEM education research, with 125 publications, substantially exceeding outputs from other nations. This prominence reflects the country's robust academic infrastructure, sustained federal funding for STEM initiatives, and its leadership role in global educational research. Following the United States, Spain (27) and China (20) have emerged as significant contributors. Spain's research output is closely linked to European Union educational frameworks, particularly in the promotion of innovative pedagogical practices and STEM teacher development. China's contributions, in contrast, are largely driven by national policies that emphasize science and

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technology as strategic priorities for economic advancement. Other notable contributors within the Asian region include Indonesia (18) and Malaysia (17), where research commonly focuses on curriculum reform, the integration of digital technologies, and strategies to foster student engagement in STEM disciplines.

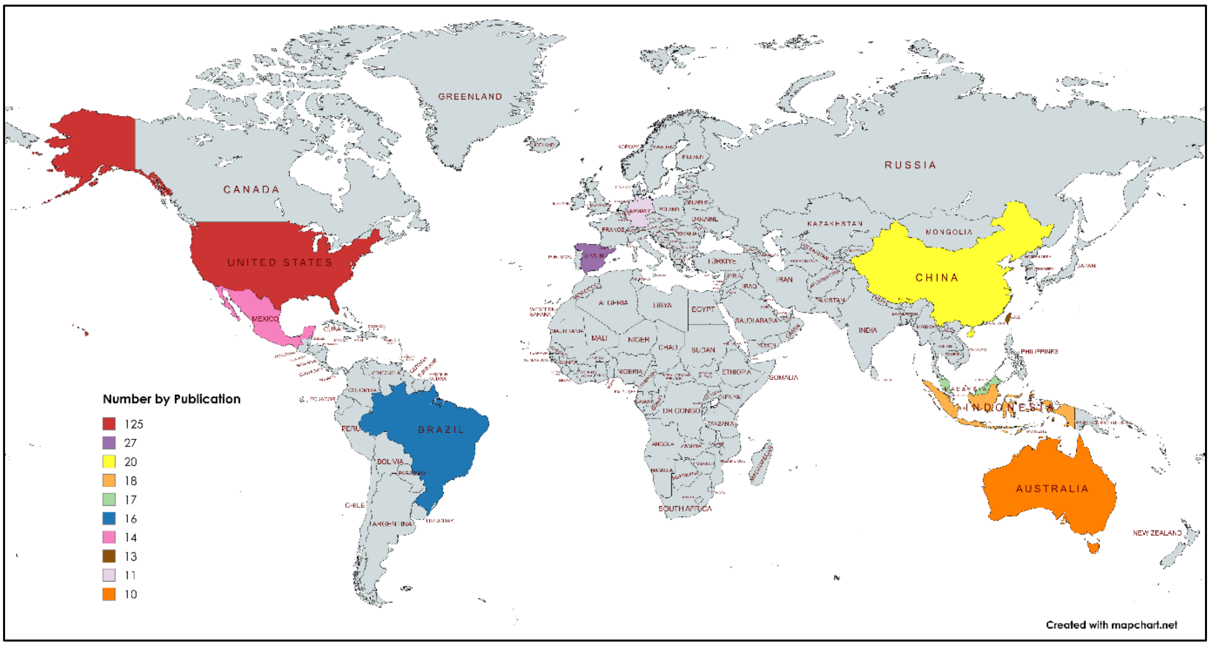

Figure 3: Top 10 Countries Based On The Number Of Publications.

Research contributions are also evident across Latin America and Europe. Brazil (16) and Mexico (14) demonstrate growing research capacity, with studies addressing educational equity, innovative methodologies, and the role of STEM in national development. Taiwan (13) has established a strong presence in technology-enhanced learning and curriculum integration, often supported by international collaborations. Meanwhile, Germany (11) continues to build on its tradition of excellence in engineering and vocational education, aligning educational research with its industrial strengths. Australia (10) completes the top ten, with research frequently addressing STEM teacher preparation, gender participation, and the design of innovative learning environments. Collectively, these findings underscore the global distribution of STEM education research, while also reflecting the diverse policy orientations and educational priorities that shape scholarly output across different regions.

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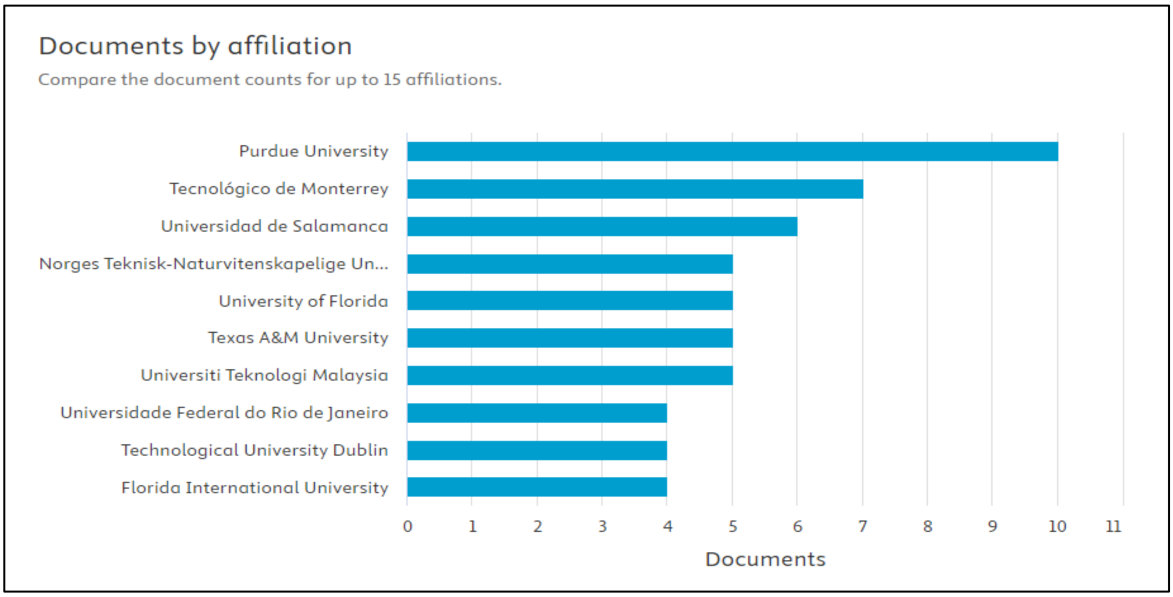

Figure 4: Documents by Affiliation.

Figure 4 in the documents by affiliation highlights the distribution of scholarly contributions across different institutions. Purdue University leads significantly with 10 documents, making it the most active contributor among the listed affiliations. This indicates a strong institutional emphasis on research in the field, possibly supported by established programs, funding, and collaborative networks. Following this, Tecnológico de Monterrey and Universidad de Salamanca show notable productivity with 7 and 6 documents, respectively, reflecting their growing involvement and emerging influence in the area. Other institutions such as Norges Teknisk-Naturvitenskapelige Universitet (NTNU), University of Florida, Texas A&M University, and Universiti Teknologi Malaysia each contributed around 5 documents, showing consistent participation. Meanwhile, universities like Universidade Federal do Rio de Janeiro, Technological University Dublin, and Florida International University produced slightly fewer outputs, with 4 documents each. Overall, while Purdue stands out as the leading hub, the contributions from a diverse set of global institutions, including North America, Europe, Latin America, and Asia, underscore the international nature of research collaboration in this domain.

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What Are Co-Occurrence, Co-Authorship, And Co-Citation Between Countries' Collaboration?

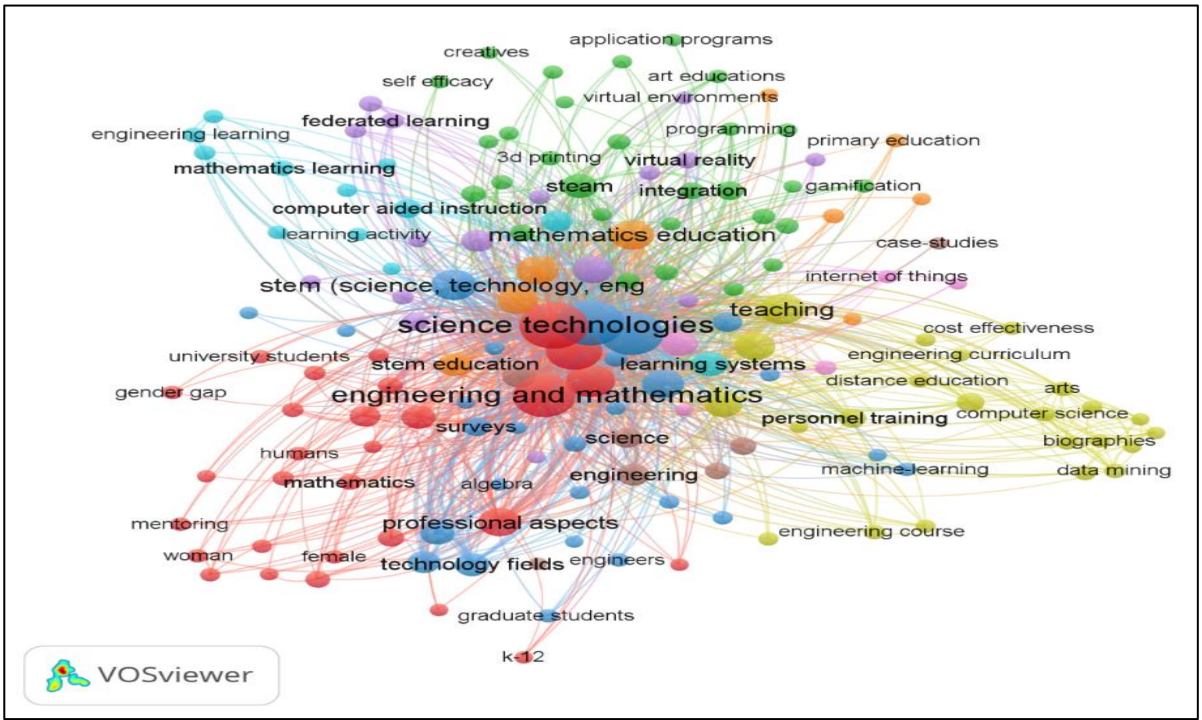

Figure 5 : Co-occurance.

The network map (Figure 5) displays clusters of related terms grouped by color, indicating thematic groupings in the research landscape. The central and most densely connected keywords—such as “science technologies,” “engineering and mathematics,” “STEM education,” and “mathematics education”—highlight core research themes. Peripheral nodes like “gender gap,” “virtual reality,” “machine learning,” and “gamification” represent emerging or niche areas within the broader STEM discourse. The size of the nodes reflects keyword frequency, while the thickness of the connecting lines indicates the strength of co-occurrence, revealing how topics intersect and contribute to interdisciplinary scholarship in STEM education and innovation (Table 3 and Table 4).

Table 3 : Network Representation of Keyword Frequency and Co-Occurrence in STEM Education Studies.

Co-occurance	Keywords	Description	Summary
High	“Science technologies” – This is the most prominent keyword, indicating a central theme in the literature. “Engineering and mathematics” “STEM education”	These keywords show strong interconnectivity, suggesting they are often studied together and are highly relevant across multiple clusters.	High-occurrence keywords are broad, foundational STEM topics.

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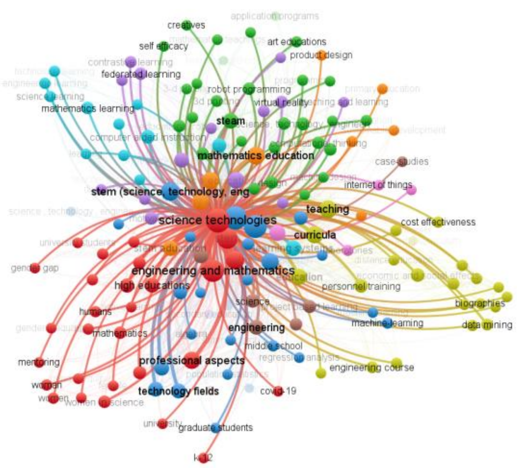
	"Mathematics education" "Learning systems" "Teaching"		
Medium	"Mathematics" "Engineering" "Programming" "Virtual reality" "Surveys" "Gender gap" "Computer science" "Distance education"	These keywords are cluster-specific, indicating focused areas of study, such as computational tools, educational equity, or remote learning.	Medium-occurrence keywords cover specific educational methods, populations, or technologies.
Low	"3D printing" "Gamification" "Mentoring" "Internet of Things" "Self-efficacy" "Art education" "Biographies" "Creatives"	These terms suggest innovative or specialized topics that may be growing in interest or represent cross-disciplinary integration (e.g., combining STEM with arts or personalization).	Low-occurrence keywords reflect emerging, experimental, or interdisciplinary interests.

Table 4 : Co-Occurrence Between Clusters.

Cluster 1		Gender, Diversity & Professional Aspects in STEM Key terms: gender gap, women, female, mentoring, professional aspects, technology fields, graduate students, university students, humans, engineers. Theme: This cluster centers on gender issues, diversity, and career pathways in STEM, especially challenges faced by women and underrepresented groups in engineering and mathematics fields.
Cluster 2		Core STEM Education and Technologies Key terms: science technologies, engineering and mathematics, STEM education, mathematics, science, technology, learning systems. Theme: This is the central and largest cluster, reflecting foundational themes of STEM integration, technological

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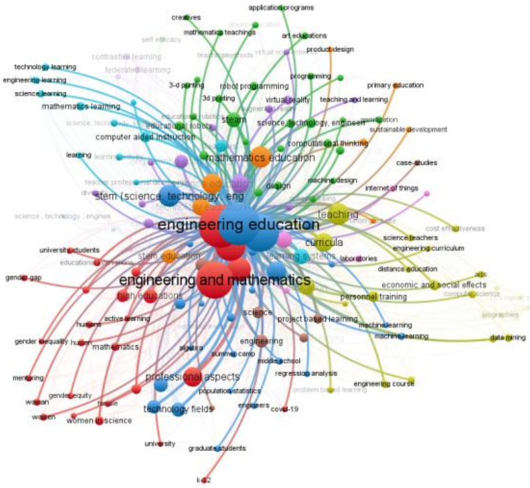
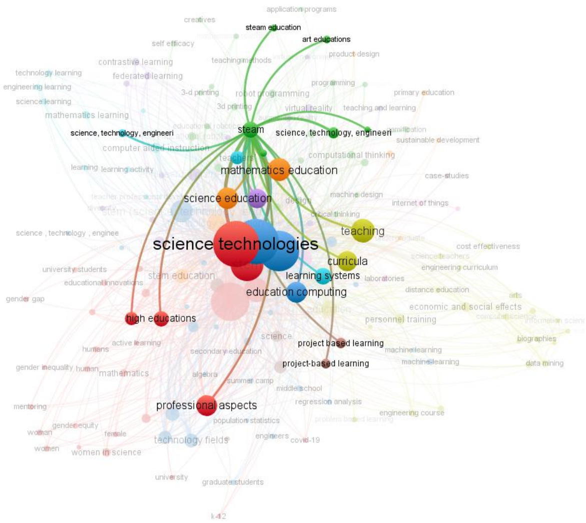


education, and interdisciplinary learning across science, engineering, and math.

Cluster 3

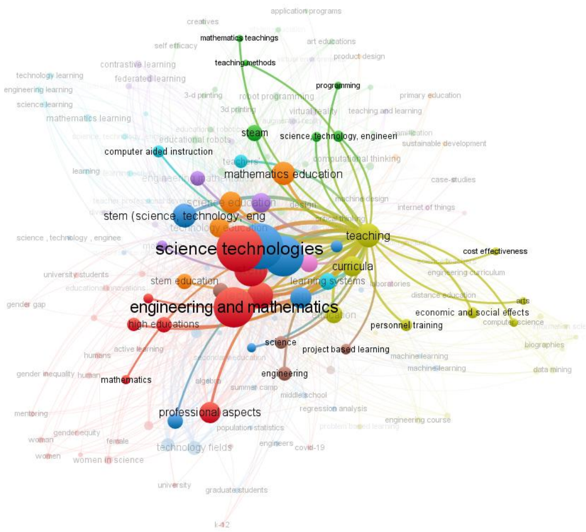


Creative and Emerging Technologies in Education

Key terms: STEAM, integration, 3D printing, virtual reality, programming, art education, virtual environments, self-efficacy, creatives, application programs.

Theme: This cluster focuses on STEAM (adding Arts to STEM) and the integration of creative technologies like VR and 3D printing into educational settings.

Cluster 4



Data Science and Engineering Curriculum

Key terms: data mining, machine learning, engineering course, computer science, biographies, arts, cost effectiveness, personnel training.

Theme: This group covers technical and analytical tools such as machine learning and data mining, along with their applications in engineering curriculum and workforce training.

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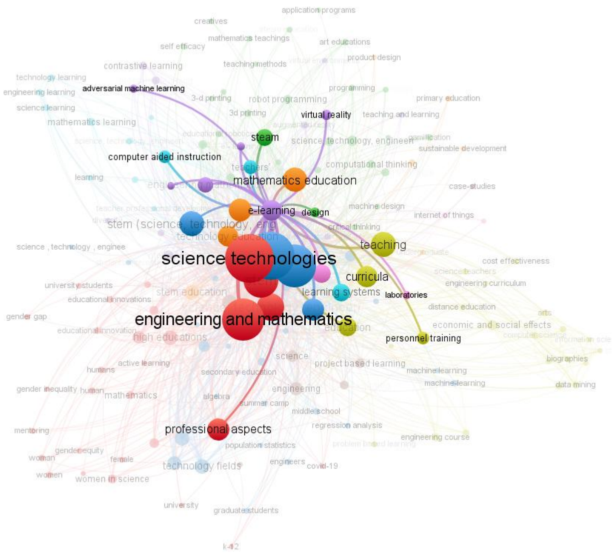
Cluster 5

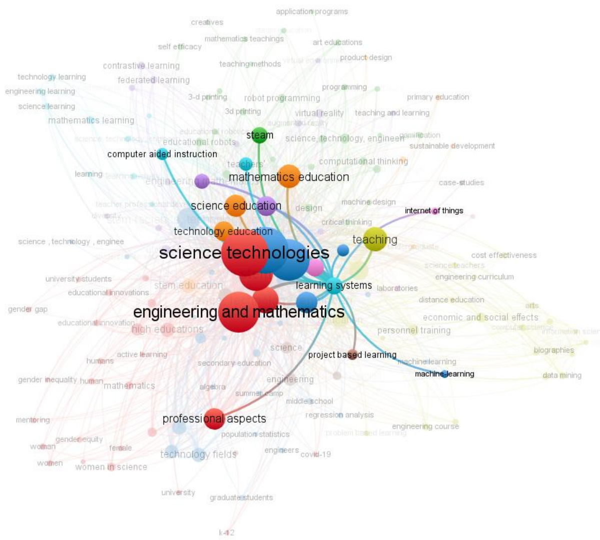


Distance Learning and Digital Pedagogies

Key terms: distance education, internet of things, case studies, engineering curriculum, teaching, cost effectiveness.

Theme: This cluster is related to digital and remote education, exploring how technologies like IoT and case-based teaching methods reshape engineering instruction.

Cluster 6



Learning Strategies & Instructional Design

Key terms: mathematics learning, computer-aided instruction, learning activity, engineering learning, federated learning.

Theme: Emphasis is on learning methods, including how AI-enabled and instructional systems support mathematics and engineering education.

Cluster 7

Primary Education & Gamification

Key terms: gamification, case studies, primary education, teaching.

Theme: This cluster looks at early-stage STEM education, especially in primary settings, and how gamified learning tools enhance student engagement.

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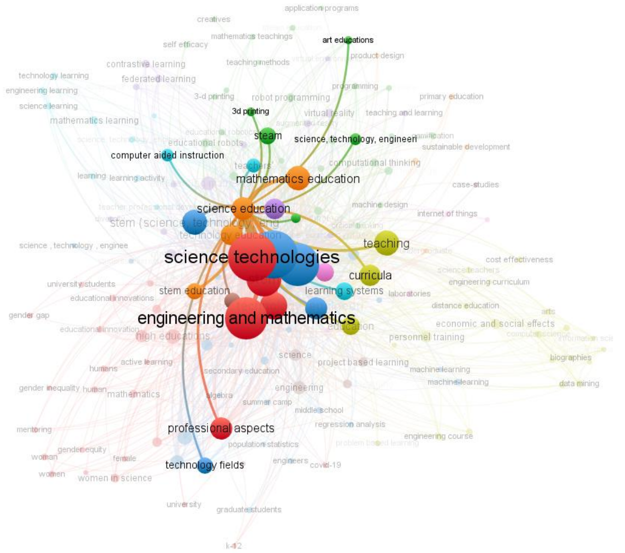
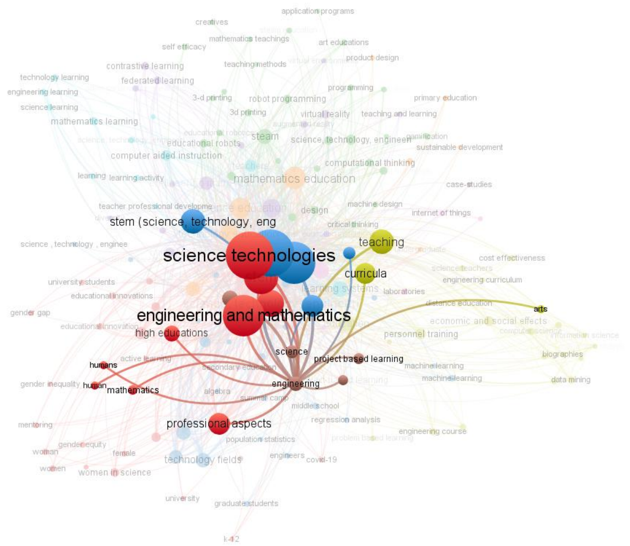


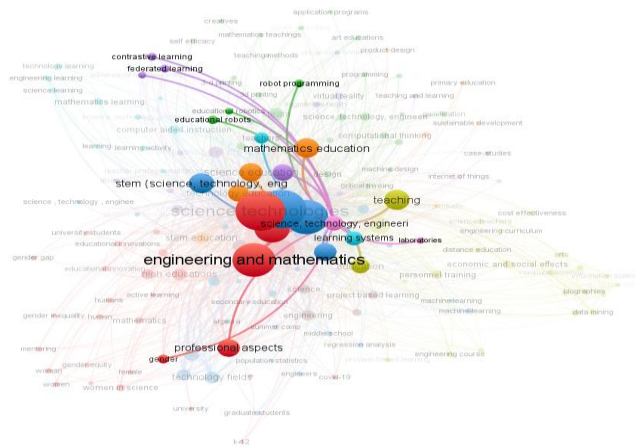
Cluster 8



Surveys and Evaluation Tools
Key terms: surveys, learning systems, STEM (science, technology, eng), k-12.

Theme: This group revolves around educational assessment, evaluation, and research methods such as surveys, especially in K-12 education systems.

Cluster 9



Teacher Training and Curriculum Support
Key terms: personnel training, teaching, curriculum.

Theme: Focuses on teacher development, training programs, and curriculum design aimed at improving STEM teaching effectiveness.

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The map (Figure 6 and Table 4) reveals geographical patterns in scholarly collaboration. The United States acts as a global hub, with Europe and Asia-Pacific forming secondary but significant collaborative regions. These patterns suggest that major research outputs are globally distributed, but dominated by a few countries with strong international ties. Regional collaboration clusters (e.g., EU, Asia-Pacific, Latin America) point to shared funding bodies, academic partnerships, or thematic focuses (e.g., education reform, digital learning).

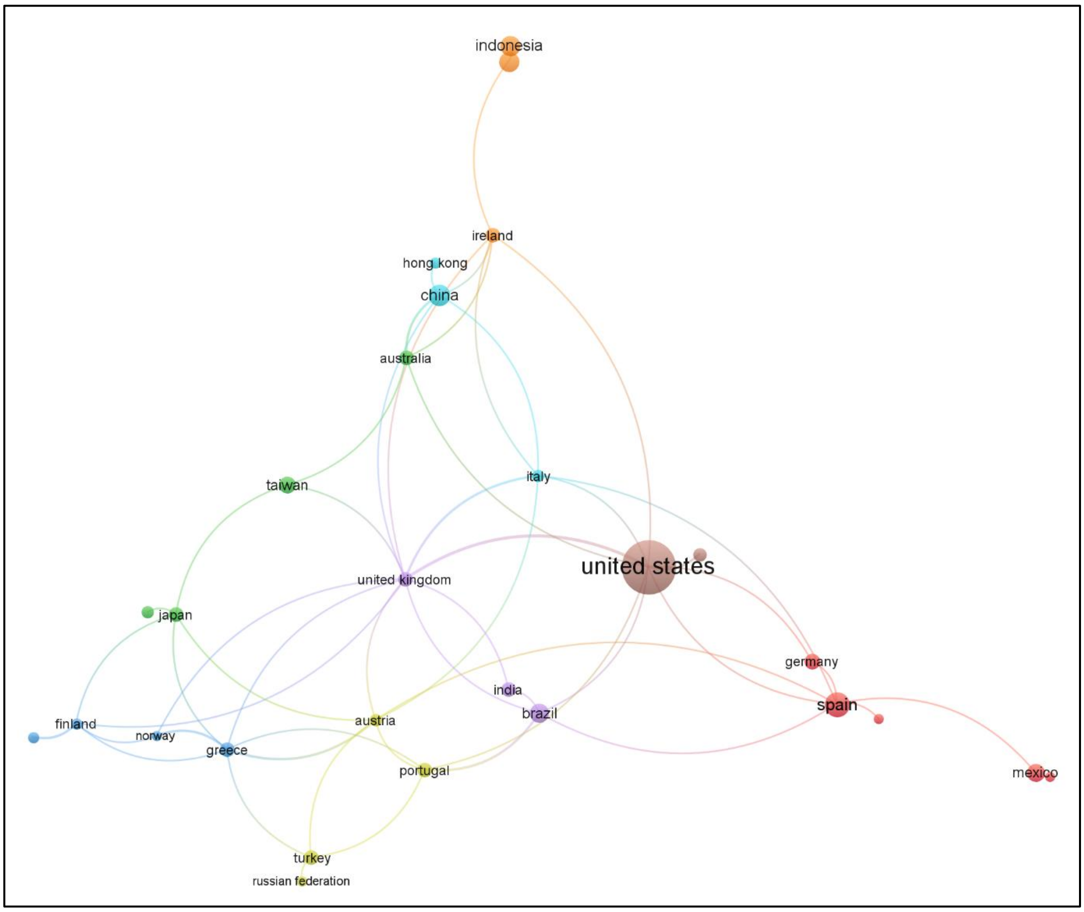
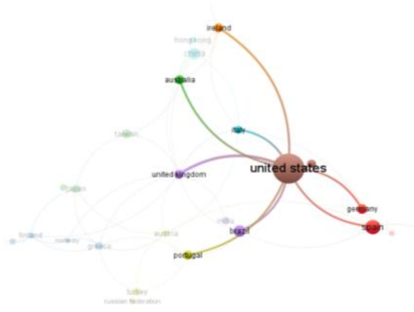


Figure 6 : Co-Authorship Between Countries.

Table 4 : Co-Authorship Between Clusters

Clusters		Observations
Main		The United States is the largest and most central node, indicating it has the highest number of publications and strong international co-authorship ties. It collaborates actively with countries such as: Spain, Germany, Italy, China, United Kingdom, India, Brazil

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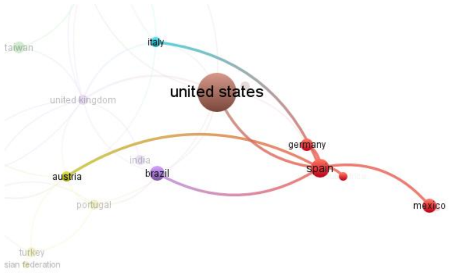
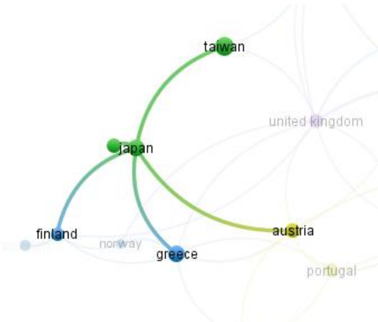
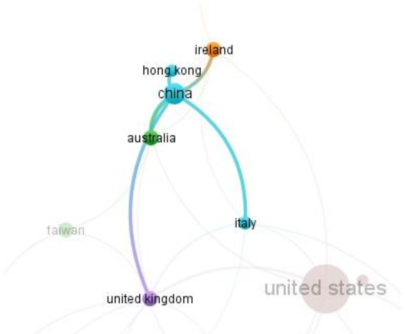
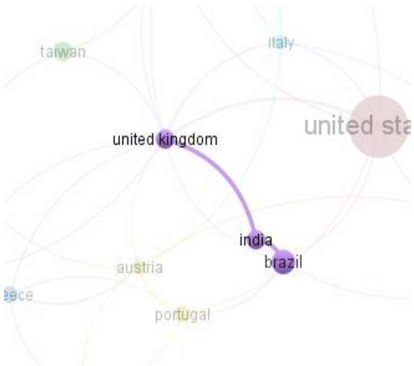
Distinct Regional		Spain, closely linked to Germany and Mexico, reflecting strong European and Latin American ties.
		Japan, Taiwan, and Australia, showing collaboration in the Asia-Pacific region.
		China, Hong Kong, and Ireland, with connections to Italy and Australia.
		United Kingdom with India, Brazil, and Austria, possibly reflecting research in Commonwealth or global education.

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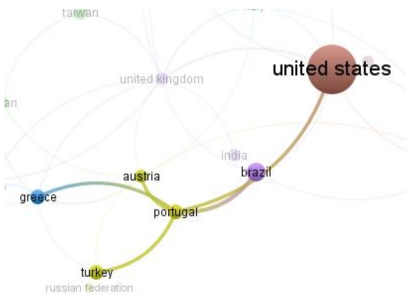
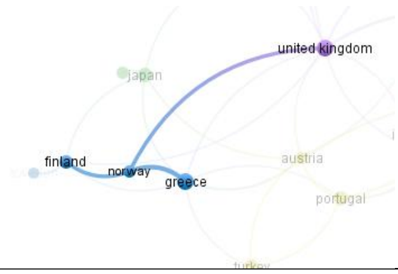
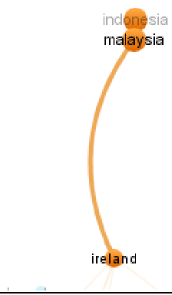
		Portugal, Turkey, Austria, Russia, and Greece, indicating cross-European academic efforts.
		Finland, Norway, and Greece, highlighting Nordic-European collaboration.
Isolated, emerging contributors		Indonesia and Malaysia, with links primarily to Ireland, indicate emerging collaborative efforts in Southeast Asia.

A co-citation analysis of authors, showing the relationship among researchers based on how frequently they are cited together in the literature (Figure 7) . In this map, each author is shown in complete isolation, with no connecting lines, indicating that these authors are not co-cited with each other. Each one may represent a separate subdomain or research niche in the broader literature. These authors are prominent enough in the dataset to appear in the co-citation analysis, but they do not share citation relationships with one another. This suggests that their contributions are influential in different strands of research—likely within the STEM or educational technology field—but their works are not cited together in the same studies. It may also reflect a fragmented citation landscape, where research is siloed by theme, region, or methodology.

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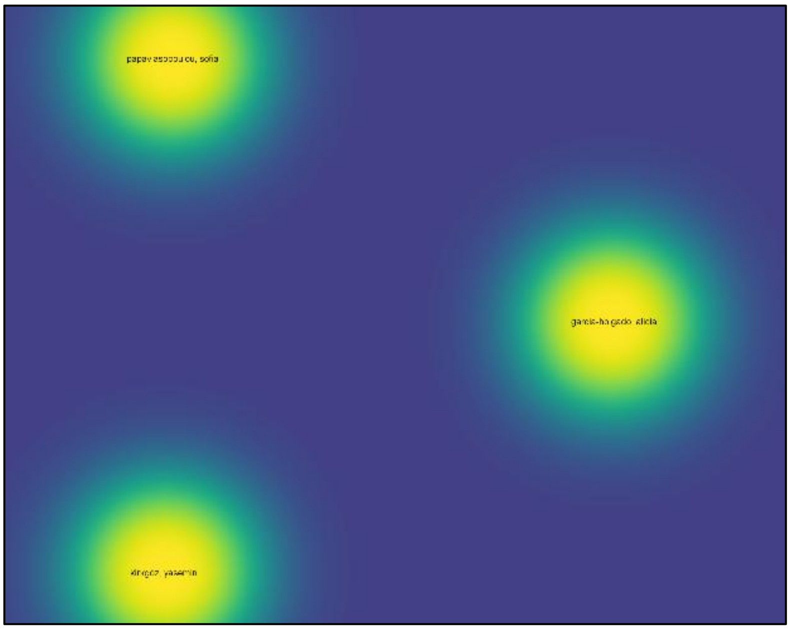

Figure 7 : Co-Citation Between Authors.

Conclusion

This bibliometric analysis provides a comprehensive overview of global research patterns in STEM education over the past decade and a half. The findings highlight a steady but modest growth in publications between 2010 and 2019, followed by a remarkable surge beginning in 2020. This rapid expansion coincides with increasing international recognition of STEM as a critical driver of innovation, economic development, and workforce readiness. Despite a slight decline in 2025, which may be attributable to incomplete indexing or delayed dissemination, the broader trend confirms the consolidation of STEM education as a prominent and maturing research domain.

The results also underscore the pivotal role of certain countries, institutions, and scholars in shaping the global landscape. The United States clearly dominates in terms of output, reflecting long-term investment and institutional strength, while countries such as Spain, China, Indonesia, Malaysia, Brazil, and Mexico demonstrate emerging influence and regional leadership. Institutional contributions reveal a diverse distribution, with strong representation from North America, Europe, Asia, and Latin America, indicating that STEM education research has become an international endeavor. Furthermore, keyword co-occurrence and collaboration analyses illustrate not only the core themes driving the field but also the rise of new areas such as gamification, virtual reality, and equity-focused approaches, all of which broaden the scope of contemporary STEM education.

Overall, this study affirms the value of bibliometric methods in identifying trends, mapping knowledge structures, and uncovering collaborative linkages across the global research community. By documenting both established and emerging directions, the analysis offers scholars, policymakers, and educators a clearer understanding of how STEM education research is evolving and where opportunities for innovation and inclusion lie. Future studies may extend these findings by integrating additional databases, applying longitudinal co-citation analyses, and examining the societal impact of STEM-related pedagogical innovations. Such efforts are essential for ensuring that the global expansion of STEM education continues to foster equity, creativity, and resilience in meeting the challenges of an increasingly complex world.

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