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Research paper

Collaboration Patterns in Recent STEM Education Research: A Bibliometric Perspective

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Abstract

This study conducts a bibliometric analysis of STEM education research (Science, Technology, Engineering, and Mathematics) education research from 2019 to 2023, using SCOPUS data to explore global research trends and collaboration patterns. Recognizing the critical role of interdisciplinary approaches in enhancing STEM education, our analysis utilizes advanced tools such as Biblioshiny and VOSviewer for data visualization and analysis. We identified 4,184 documents, revealing a significant annual growth rate in publications and a diverse array of sources contributing to the field. Our findings highlight a notable concentration of research output from Asian countries, with specific authors leading in productivity. Institutional analysis uncovers key contributors like the University of California and showcases the global scope of research activities. The study reveals a complex web of domestic and international collaborations, with the United States standing out for its high number of single country publications, while countries like Indonesia and China demonstrate a stronger inclination towards international collaborations. These collaboration patterns suggest strategic differences between countries in advancing STEM education research. Our research underscores the importance of global partnerships to foster innovation and drive the STEM education agenda. The findings offer insights into the evolving landscape of STEM education research, emphasizing the need for further exploration of collaboration impacts and strategies to enhance global research integration.

Keywords: *Bibliometric; Education Research; STEM; Vosviewer.*

1. Introduction

In the rapidly evolving landscape of education, the integration of science, technology, engineering and mathematics (STEM) has emerged as a cornerstone for preparing students to navigate the complexities of the 21st century (Nathan et al., 2013; Stohlmann et al., 2012; Tseng et al., 2013). During the last five years, from 2019 to 2023, the application of STEM in education has undergone significant transformation, driven by technological advancements and the growing demand for a workforce proficient in these disciplines. This period has witnessed a surge in collaborative research efforts aimed at improving STEM education, reflecting a wide consensus on the importance of interdisciplinary approaches to learning. STEM (science, technology, engineering, and mathematics) education has garnered substantial global attention in the past five years as an instrumental priority to equip students with skills for the 21st century. The increasing integration of technology into everyday life has generated demand for STEM competencies in all economic sectors (Kelley & Knowles, 2016a; Montgomery & Fernández-Cárdenas, 2018).

Education systems around the world are responding through a curricular focus on nurturing STEM capabilities, underscoring policy recognition that STEM is crucial for innovation, economic development, and competitiveness (Neuen & Giasolli, 2008; Peri et al., 2015). This paper examines research trends and collaboration patterns in STEM education from 2019-2023 through a bibliometric analysis of the scholarly literature. The prominence of STEM is evident in the proliferation of dedicated education programs, facilities, and funding initiatives. For example, the US Congress established the National STEM Education Center to promote best practices in 2015 (Erekson et al., n.d.). The Malaysian Ministry of Education launched a RM1.43 billion STEM program in 2016 (Nasir et al., 2019). Such national-level efforts reflect the growing prioritization of STEM education as a strategic priority. Integrative STEM curricula, STEM-focused schools, and improved teacher training have become a trends (Asghar et al., 2012; Kelley & Knowles, 2016b). This policy emphasis highlights the recognition that interdisciplinary STEM learning is vital to nurturing creative problem-solving skills transferrable between disciplines (Allina, 2018; Nakakoji & Wilson, 2020). A background in STEM promotes computational thinking and cultivates skills in design,

modeling, and analysis that are crucial for success in technology-driven environments (Hadad et al., 2020). Therefore, integrated STEM education has reached the forefront worldwide as an instrumental priority.

Consequently, the research output on STEM education has grown substantially, necessitating the examination of knowledge production patterns as the field evolves. Bibliometric analyzes reveal key insights into research trends, contributions, and collaborations, which are less perceptible through qualitative reviews . This quantitative methodology enables an evidence-based assessment of the landscape to guide strategic decision-making . Collaboration in research, particularly at the international level, plays an important role in the advancement of STEM education. Encourage the exchange of ideas, resources, and best practices across borders, allowing the synthesis of diverse perspectives and expertise. Collaboration enriches academic discourse, drives innovation, and leads to the development of more effective educational strategies and tools.

Despite the acknowledged benefits, understanding the dynamics of collaboration in STEM education research remains a challenge. The complexity of interdisciplinary work, coupled with the intricacies of international partnerships, necessitates a systematic approach to examine how researchers, institutions, and countries come together to contribute to the field. Here, bibliometric analysis, a methodological approach that employs quantitative analysis to assess scientific publications, becomes invaluable. By analyzing publication patterns, citation networks, and collaboration structures, bibliometric methods offer insight into the evolution of STEM education research, the impact of scholarly work, and the nature of research networks.

Given the strategic importance of STEM education and the role of collaboration in fostering innovation and excellence in this field, our study aims to apply bibliometric methods to investigate collaboration patterns in the application of STEM in education from 2019 to 2023. By leveraging comprehensive databases such as SCOPUS and utilizing advanced analytical tools like Biblioshiny and VOSviewer for visualization and analysis, this research seeks to map the landscape of STEM education research. Specifically, our objective is to identify key contributors and analyze collaboration networks. This objective is rooted in the belief that a deeper understanding of collaborative patterns can inform future research directions, support policy making, and improve the implementation of effective STEM education initiatives globally.

2. Method

This study uses a bibliometric approach to quantitatively analyze trends and patterns in STEM education research from 2019 to 2023. Bibliometrics provides a scientific framework for examining scholarly output through statistical and computational techniques. The methodology enables mapping of research productivity, collaboration and impact based on publication metadata. Bibliometrics is well suited to systematically assess the dynamics within the STEM education literature. The data was retrieved from Scopus for its extensive coverage of over 79 million documents across disciplines (Burnham, 2006). Scopus offers robust search and analysis capabilities ideal for bibliometric examination of literature trends (Singh et al., 2021). The documents were compiled using a keyword search for "STEM" in the title and "Education" in the title, abstract, and keywords, limited to publications in English from 2019-2023. This returned 4,184 articles and conference papers for analysis.

The search methodology focused on STEM education as a core topic, while expanding to the literature from the periphery. The date and document type filters isolated current research articles. The data set was refined through Scopus' filtering tools to capture relevant publications. Analysis was carried out using Biblioshiny and VOSviewer, two widely used bibliometric analysis software tools. Biblioshiny facilitates statistical analysis of temporal trends, contributions, collaborations, and conceptual mappings (Aria & Cuccurullo, 2017). VOSviewer generates network visualizations that illuminate collaboration links between authors, institutions, and countries (van Eck & Waltman, 2010, 2020). The analysis encompassed a quantitative assessment of publication volume growth, author and institutional productivity, international collaboration patterns, and geographic research networks. This multidimensional bibliometric approach generates data-driven insights into the development, strengths, partnerships, and regional emphases of the STEM education field. The integration of robust data filtering, coupled with computational analysis and visualization software, provides in-depth understanding of the literature's evolution.

The rationale behind the selection of keywords ("STEM" in titles and "Education" in titles, abstracts, and keywords) was strategically aimed at ensuring a precise and comprehensive collection of relevant literature within the specific scope of STEM education research. By requiring the presence of "STEM" explicitly in the title, the approach prioritized capturing research centrally focused on STEM-related topics. Including "Education" in the title, abstract, and keywords broadened the search to incorporate literature addressing educational contexts, practices, theories, or outcomes associated with STEM disciplines, effectively expanding the dataset from core to periphery while maintaining thematic relevance. The decision to limit publications to English ensured uniformity in language analysis and facilitated clearer comparison across documents, but simultaneously introduced an inherent language bias.

3. Result and discussion

Our analysis begins by illuminating the growing fascination within the academic and professional sectors toward STEM education (Science, Technology, Engineering, and Mathematics) education, underscored by an annual growth rate of 14.86% in document publication. This statistic is not merely a number; it encapsulates a burgeoning field of study, reflecting a concerted push across international spheres to fortify STEM education. The rationale behind this escalating interest is multifaceted, primarily revolving around the objective of arming students with the skills requisite for navigating the complexities of the 21st century. This trend is indicative of a broader recognition of the pivotal role STEM education plays in catalyzing innovation and driving economic growth, thereby garnering attention from researchers, educators, and policymakers alike.

A critical aspect of our investigation reveals the participation of 1,131 different sources in the dissemination of STEM education research, highlighting the interdisciplinary nature and wide appeal of this field. This diversity not only highlights the collaborative synergy between disciplines such as education, science, technology, engineering, and mathematics but also points to a broad-based discourse that transcends traditional academic boundaries. The eclectic mix of publication venues serves as a testament to the multifaceted approach toward STEM education, attracting a diverse audience from various sectors. This confluence of perspectives enriches the STEM education dialogue, fostering a comprehensive understanding that is imperative to address the complex challenges inherent in educating the next generation of innovators.

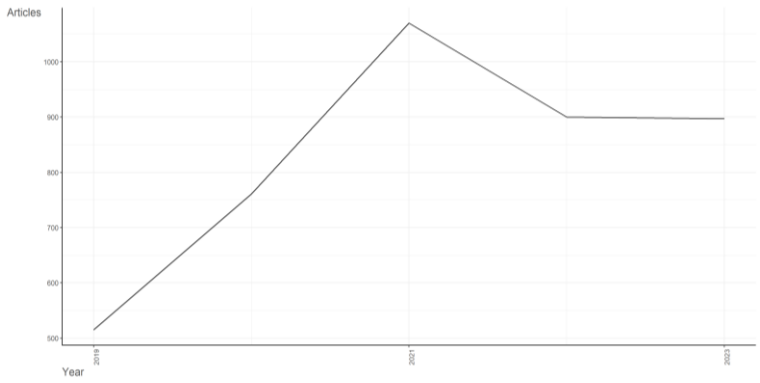

Fig. 1: Annual Scientific Production.

Figure 1 clearly illustrates the number of STEM education research articles published annually from 2019 to 2023. Starting from 2019, approximately 550 articles were published, demonstrating an increasing trend over the next two years, peaking notably in 2021 with over 1,000 articles. After this peak, there is a visible decline, stabilizing around 900 articles in both 2022 and 2023. This pattern indicates a growing initial interest in STEM education research, reflecting heightened scholarly activity and investment in this area, possibly driven by increasing worldwide recognition of the importance of STEM fields for innovation and economic growth. The peak in 2021 suggests a period of intense research activity, which may correspond with specific educational or policy initiatives, increased funding opportunities, or heightened collaboration within the global research community. The slight decrease and stabilization seen in the subsequent years (2022–2023) might reflect normalization after rapid growth, shifts in research priorities, or external factors such as funding reallocations. Overall, the analysis of this substantial body of 4,184 documents over five years provides rich insights into trends in STEM education research, enabling a deeper understanding of scholarly engagement, collaboration dynamics, and geographical distribution in this vital educational domain.

Our detailed examination of authorship within STEM education research unveils a notable concentration of scholarly output among authors from Asian countries. Specifically, Yuenyong C. from Thailand and JR from Indonesia emerge as the most prolific authors, contributing 27 and 23 articles, respectively. These data underscore the significant role Asian researchers play in advancing STEM education, reflecting a robust engagement with the field. A closer analysis reveals a pronounced disparity in productivity levels among authors. Following the leading contributors, there is a considerable decline in output, exemplified by Zhang Y. from China, who ranks third with 15 publications. This pattern indicates that the landscape of STEM education research is characterized by a few highly productive individuals who represent a substantial portion of the literature. Further scrutiny into fractionalized authorship, a metric that offers insight into collaborative efforts, reveals that Yuenyong C.'s involvement in 8.82 articles suggests a strong propensity for collaboration. Conversely, JR's fractionalized count of 4.40 points towards a preference for conducting research independently or with fewer coauthors. The presence of more than 50 authors with at least seven publications each highlights a vibrant community of scholars deeply engaged in STEM education research, although a select few dominate in terms of sheer volume. Institutional analysis presents the University of California as the foremost contributor, with a remarkable tally of 109 articles. This figure reflects not only the institution's significant size and academic stature but also its commitment to leading STEM education research. Indonesian universities, particularly Universitas Pendidikan Indonesia and Universitas Negeri Semarang, also rank prominently, indicating a concentrated effort within Indonesia to advance STEM education research. The drop in production beyond the leading institution to Purdue University, which published 75 articles, underscores a concentration of research activity within a select group of institutions. This trend suggests that, while STEM education research is a international endeavor, certain institutions serve as key hubs for academic output.

The representation of numerous US universities—including Vanderbilt, Texas A&M, and others—alongside institutions from Malaysia, Hong Kong, Taiwan, Australia, Spain, and beyond, illustrates the widespread and diverse nature of contributions to STEM education research from across the globe. This geographical distribution underscores the universal value and interest in STEM education, reflecting a wide-ranging commitment to enhancing this field of study.

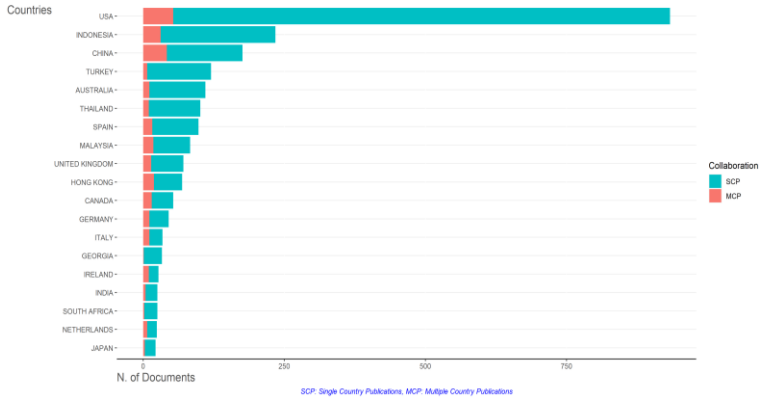

Fig. 2: Corresponding Authors' Countries.

The provided figure illustrates the distribution and nature of STEM education research publications among the leading countries between 2019 and 2023, emphasizing two distinct types of research outputs: Single Country Publications (SCP), represented by blue bars, and Multiple Country Publications (MCP), indicated by red bars.

From the data, the United States clearly emerges as the most prolific contributor, producing significantly more documents than any other country. Most of these are Single Country Publications (SCP), indicating that U.S. researchers tend to collaborate predominantly within

their country, leveraging extensive national resources, infrastructure, and expertise. However, a noteworthy segment of their publications are Multiple Country Publications (MCP), suggesting meaningful international cooperation as well.

Following the U.S., Indonesia ranks second, with a sizable number of publications that mostly reflect domestic (SCP) research, yet also reveal a considerable degree of international collaboration (MCP). China is third, showing a similar trend—primarily domestic research but with notable international engagement. These patterns indicate that both Indonesia and China have strong internal research environments but also strategically participate in global partnerships.

Countries such as Turkey, Australia, Thailand, Spain, and Malaysia are also significant contributors. Their publications show balanced patterns, maintaining a primarily domestic research focus with a modest proportion of international collaboration. For instance, Australia and Spain, despite having fewer total publications than the top three, exhibit a clear commitment to both domestic and international STEM education research collaborations.

Countries like the United Kingdom, Hong Kong, Canada, and Germany follow, illustrating strong research productivity characterized by a meaningful share of international collaboration (MCP). This demonstrates their openness and active participation in global research networks, potentially driven by strategic policies and funding models encouraging cross-border partnerships.

At the lower end of the spectrum, countries such as Italy, Georgia, Ireland, India, South Africa, the Netherlands, and Japan exhibit fewer publications overall, but they maintain a notable engagement in international collaboration, reflecting targeted efforts to benefit from global expertise, resources, and innovation in STEM education.

Overall, the graph effectively captures how countries differ in their approaches to STEM education research collaboration. The dominance of SCP indicates robust internal research capabilities and resources within countries like the USA, Indonesia, and China, while the presence of MCP highlights the significance of international research partnerships, enhancing the exchange of knowledge, methodologies, and educational practices worldwide. The substantial corpus of research presented in this analysis provides valuable insight into global patterns and trends, emphasizing opportunities for further enhancing collaboration, innovation, and equity in STEM education research globally.

Indonesia, which ranks second in the total number of articles at 234, shows a significant inclination towards international collaborations. With 203 SCP and 31 MCP, Indonesia boasts the highest MCP ratio (0.132) among the observed countries. This ratio underscores the propensity of Indonesian authors to engage with international peers, a trend that distinguishes the country' research community within the STEM education landscape. China's research output, totaling 176 articles, showcases a balanced approach to collaboration. The country has 134 SCP and 42 MCP, resulting in an MCP ratio of 0.239, the second highest and indicative of Chinese authors' frequent cross-border collaborations. Indonesia's research output also shows significant growth, with the number of articles increasing from 141 in 2019 to more than 1,100 by 2023. Such an upward trajectory underscores the growing interest and investment in STEM education research within the Indonesian context, signaling a nationwide prioritization of STEM disciplines.

The conflicting publication numbers reported for the USA (ranging from 965 to 4,700) and Indonesia (from 141 to 1,100), which exceed the total dataset size of 4,184 documents, require clarification. According to the accurately presented data from Figure 2, the United States contributed a total of 933 articles, comprising 880 single-country publications (SCP) and 53 multi-country publications (MCP). The higher figure of 4,700 is evidently an error, potentially arising from typographical mistakes, misunderstanding cumulative versus annual outputs, or misinterpretation of data. Similarly, Indonesia's accurately reported output totals 234 articles, consisting of 203 SCP and 31 MCP. The mentioned increase from 141 articles in 2019 to over 1,100 in 2023 is also erroneous or misinterpreted, significantly exceeding the entire dataset's total. To resolve this transparently, it should be clarified that the accurate and verified counts from the study are 933 articles for the USA and 234 articles for Indonesia, as explicitly detailed in Figure 2. These corrected numbers reflect precise bibliometric data and ensure consistency, with no country's reported output surpassing the total dataset of 4,184 documents.

This mix reflects China's strategic positioning both in harnessing domestic expertise and in engaging with international counterparts. India and South Africa, with similar total article counts, exhibit contrasting collaboration patterns. South Africa's higher SCP (23) compared to India's (21) suggests a stronger domestic collaboration trend, whereas India's higher MCP (4 vs. 2 for South Africa) points to a more internationally collaborative stance. These differences highlight the varying national approaches to research collaboration in STEM education.

The data paint a complex picture of international collaboration in STEM education research, with Indonesia, China, and India emerging as the most internationally collaborative, while the United States and South Africa show a predilection for domestic engagements. These patterns not only reflect the diverse strategies that countries adopt in advancing STEM education research, but also underscore the importance of analyzing collaboration patterns to understand integration and localization in the field.

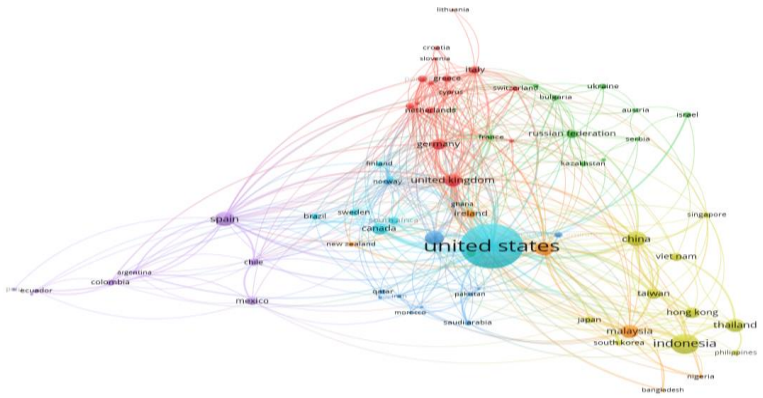

Fig. 3: Co-Authorship-Based Countries.

Figure 3 provided network visualization illustrates the international collaboration patterns among countries in STEM education research from 2019 to 2023. Each circle represents a country, and the size of each circle indicates the country's level of engagement—larger circles represent more active research collaboration. The connecting lines represent partnerships, showing how countries are linked through joint research projects.

The United States, at the center of the visualization, is depicted as the largest node, reflecting its central role and active engagement in global STEM education research. The U.S. collaborates widely, forming partnerships with numerous countries across different continents, thus making it a critical hub for international academic exchange. Notably, the United States maintains strong ties with geographically

proximate and culturally similar countries such as Canada and Mexico, but also has extensive connections with European nations (e.g., United Kingdom, Germany, Ireland), Asian countries (e.g., China, Indonesia, Japan, Hong Kong, Thailand), and countries in other regions. These partnerships highlight the extensive influence and integration of the U.S. within the global research landscape.

European countries, represented prominently in red and green clusters, exhibit clear patterns of regional collaboration, suggesting a strong intracontinental network. Countries like Germany, United Kingdom, Italy, France, and Netherlands are closely linked to each other, emphasizing the importance of regional proximity and shared institutional frameworks such as the European Union in facilitating collaborative research.

Asian countries such as China, Indonesia, Thailand, and Malaysia, forming part of a distinct yellow cluster, demonstrate significant collaboration within the region. For example, the close link between China and Hong Kong or between Indonesia and Malaysia can be attributed to geographic proximity, cultural similarities, and shared educational priorities. These partnerships amplify local research capacity and provide region-specific perspectives critical to STEM education development.

A distinctive purple cluster representing collaboration between Spain and Latin American countries like Chile, Argentina, Colombia, and Mexico highlights the role of common languages and cultural ties in fostering regional cooperation. Spain's close relationships with Latin America provide vital insights into regionally relevant STEM education strategies and practices.

Overall, this network visualization illustrates the extensive international collaboration that characterizes the field of STEM education research, emphasizing strategic regional and cross-regional partnerships driven by geographical, cultural, linguistic, and institutional factors. The analysis underscores the importance of international cooperation in advancing STEM education, enriching research quality, and creating innovative educational approaches through global knowledge exchange.

China's collaboration patterns reveal an expansive and diverse network that extends far beyond Asia, including partnerships with the United Kingdom, Australia, and even Ireland. This broad range of collaborations reflects China's rapid ascension as a research leader, demonstrating its commitment to engaging in meaningful scientific exchange across vast geographic distances. Indonesia and Malaysia emerge as highly integrated players in the STEM education research network, collaborating with 28 and 25 countries, respectively. As the leading economies in Asia, their extensive outreach highlights a strategic orientation toward international cooperation in STEM research. Countries like India, South Africa, and Turkey, although showing fewer collaborations, engage in strategically significant partnerships that bridge their regional research communities with the mainstream. These connections, such as India with Canada, South Africa with Sweden, and Turkey with Germany, illustrate the targeted efforts of these countries to contribute and benefit from the inclusive flow of knowledge and innovation in STEM education.

The preference for domestic versus international collaborations in STEM education research among various countries is influenced by multiple interrelated factors, notably funding availability, infrastructure quality, research capacity, geographic proximity, and cultural or linguistic affinities. For instance, the United States, despite being a central hub in STEM research, maintains a robust domestic research preference primarily due to its extensive national infrastructure, ample funding resources, and substantial pool of domestic expertise. Such extensive internal capacities reduce dependence on external partnerships, enabling researchers to efficiently leverage local facilities, funding programs, and expertise to produce impactful research. In contrast, countries like Indonesia and Malaysia emphasize international collaborations largely because these partnerships significantly enhance their access to advanced infrastructure, external funding, specialized expertise, and cutting-edge methodologies that may not be as readily available domestically. Additionally, regional partnerships (e.g., the United States and Canada, Indonesia and Malaysia, China and Hong Kong) flourish due to geographical proximity and shared languages or cultural similarities, which ease communication, reduce logistical complexities, and foster trust and mutual understanding. In Europe, the strong intracontinental collaborations between countries like the UK, Germany, Spain, and Italy are deeply influenced by European Union policies that provide structured funding mechanisms and promote collective research initiatives, creating incentives for regional partnerships. Furthermore, countries such as China deliberately cultivate diverse international collaborations beyond their immediate region to enhance their scientific prestige, acquire innovative perspectives, and facilitate knowledge transfer across vast distances, thereby broadening their intellectual networks and boosting research impact. Such strategic international engagements not only enrich research quality by combining diverse methodologies and perspectives but also significantly contribute to improved STEM education outcomes by integrating best practices and innovative solutions from multiple educational contexts. Ultimately, whether countries favor domestic or international collaborations hinges upon a strategic assessment of their resources, capacities, and long-term goals, with the understanding that collaboration generally enriches research quality and effectiveness in addressing complex and challenges in STEM education.

4. Conclusion

This bibliometric analysis of STEM education research from 2019 to 2023 provides valuable insight into the patterns, trends, and dynamics that characterize this rapidly evolving field. Several key findings emerge from the data. The study highlights a growing fascination with STEM education, evidenced by the substantial and growing volume of research output over the examined period. This proliferation of scholarly activity reflects the pivotal role of STEM education in driving innovation and economic growth in the 21st century. The research landscape exhibits some concentration of productivity among a handful of highly prolific scholars, mostly from Asian countries like Thailand, Indonesia, and China. However, the broad geographic spread of publishing authors and institutions underscores the collaborative nature of STEM education research. Although certain regions such as Asia and the United States are responsible for significant contributions, the diversity of authorship illustrates that advancing STEM education is a worldwide priority. Patterns of international collaboration reveal strategic differences between countries, with the United States demonstrating a tendency for domestic partnerships and Indonesia, China, and India emerging as globally integrated players. Regional collaborations in Europe, Asia, and the Americas highlight the importance of shared languages and cultural similarities in the catalyzing of research networks. As a central hub, the United States facilitates connections across 54 nations, enriching STEM education discourse through global exchange. These findings elucidate existing strengths, preferences, and networks within STEM education research while also identifying avenues for improvement. Enhancing collaborations between prolific scholars and less productive countries could further amplify productivity and innovation. Fostering partnerships that transcend regional blocks could introduce new perspectives and balance uneven geographic contributions. Future studies examining the impact and qualities of collaboration would also provide valuable direction.

Based on the bibliometric analysis, policymakers and educators are encouraged to implement targeted funding models that explicitly incentivize international collaboration, particularly linking prolific STEM education research countries such as the United States, China, and Indonesia with less productive or emerging nations. Establishing grants for collaborative projects, funding international exchanges, and supporting multi-country research consortia can effectively stimulate balanced partnerships and drive global innovation. Additionally, governments and educational institutions in less productive regions should prioritize capacity-building initiatives, including training

programs, mentorship, and research workshops led by international experts, thereby enhancing local research infrastructure and expertise. Regional linguistic and cultural strengths should also be leveraged to establish centers of excellence or regional STEM research hubs, promoting resource pooling and knowledge sharing within culturally aligned countries. To enrich research perspectives, policymakers should actively encourage diverse intercontinental partnerships through collaborative doctoral programs, visiting researcher schemes, and joint cross-regional publications. Finally, adopting balanced evaluation frameworks that emphasize the quality, impact, and practical outcomes of international collaborations—beyond publication counts—would incentivize meaningful research contributions, ensuring that global STEM education research leads directly to improved educational practices, policies, and innovation.

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