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A Bibliometric Analysis of iSTEM Research: Trends, Collaboration, and Emerging Themes

Sumaiyah Mohd Zaid, Norulhuda Ismail

Faculty of Educational Sciences and Technology, Universiti Teknologi Malaysia, Johor, Malaysia

Email: p-norulhuda@utm.my

Corresponding Author Email: sumaiyahmohdzaid@graduate.utm.my

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Abstract

iSTEM in education is an interdisciplinary approach that integrates Science, Technology, Engineering, and Mathematics (STEM) with inquiry-based and hands-on learning to develop critical thinking, problem-solving, and real-world application skills. This study aims to analyze the trend, structure, and thematic evolution of iSTEM research by examining indexed academic publications. This study does a bibliometric analysis of iSTEM (Intergrated Science, Technology, Engineering, and Mathematics) research to discern key trends, prominent authors, significant publication sources, and rising research issues. This study examines the progression of iSTEM research through an analysis of indexed academic papers, investigates collaboration patterns among academics, and identifies the most utilized keywords. The results indicate substantial expansion in iSTEM-related research, emphasizing multidisciplinary partnerships and technical progress. The research additionally introduces a term network to depict the conceptual progression of the discipline. These insights offer a blueprint for future study, assisting scholars and policymakers in formulating effective research methodologies and multidisciplinary frameworks.

Keywords: Bibliometric Analysis, iSTEM, Research Trends, Collaboration Network, Emerging Themes.

Introduction

The rapid advancement of technology and the increasing demand for interdisciplinary approaches in education and research have positioned Integrated Science, Technology, Engineering, and Mathematics (iSTEM) as a crucial academic discipline. iSTEM research seeks to merge multiple fields to enhance scientific discovery, technological innovation, and educational practices, addressing complex real-world challenges through interdisciplinary collaboration. As nations emphasize STEM education to drive economic growth and innovation, understanding the evolution, impact, and collaborative patterns of iSTEM research has become increasingly important.

A bibliometric analysis of iSTEM literature is essential for mapping the research landscape, identifying influential publications, and evaluating collaboration trends. By examining

scholarly output, citation patterns, and thematic developments, bibliometric analysis provides a quantitative assessment of research progress and highlights key contributors, emerging topics, and gaps in the literature. Such insights are valuable for researchers, educators, and policymakers seeking to enhance interdisciplinary collaboration and design effective research frameworks in STEM education.

This study aims to analyze the trend, structure, and thematic evolution of iSTEM research by examining indexed academic publications over a specified period. The study investigates publication trends, co-authorship networks, journal impact, and keyword distributions to understand how iSTEM research has progressed over time. Additionally, the study introduces a term network analysis to visualize conceptual advancements in the field. The findings offer a strategic roadmap for future research, providing valuable insights for academics, institutions, and policymakers in shaping the next phase of iSTEM education and research.

Literature Review

Integrated STEM (iSTEM) education has arisen as a pivotal pedagogical strategy designed to augment student engagement and comprehension in the domains of Science, Technology, Engineering, and Mathematics. This method highlights the interrelation of several fields, fostering a comprehensive understanding essential for tackling intricate real-world issues. The literature emphasizes numerous critical facets of iSTEM education, including its design principles, educator readiness, and effects on student outcomes.

A principal obstacle in implementing iSTEM education is the necessity for effective observation protocols to assist educators in evaluating and enhancing their teaching methodologies. Ong et al. present a comprehensive STEM classroom observation protocol that rectifies deficiencies in earlier frameworks by delineating consistent design principles and pedagogical goals, crucial for promoting effective disciplinary interaction in the classroom (Ong et al., 2023). This framework is essential for guaranteeing that iSTEM education is both executed and assessed effectively, facilitating ongoing enhancement of pedagogical approaches.

Furthermore, the professional advancement of educators is essential for the effective incorporation of iSTEM into the curriculum. Arnone and Hanuscin delineate prevalent hurdles encountered by elementary educators in conceptualizing and executing iSTEM education, underscoring the necessity for specialized professional development initiatives that tackle these issues (Arnone & Hanuscin, 2018). Martins examines how teacher professional development in integrated STEAM education fosters the enhancement of pedagogical content knowledge (PCK) among physics educators, hence improving their capacity to teach iSTEM effectively (Martins, 2024). This underscores the necessity of providing educators with the requisite skills and expertise to effectively implement integrated STEM courses.

The influence of iSTEM education on student learning outcomes is a matter of considerable attention. Research demonstrates that iSTEM techniques, like the VH-iSTEM learning strategy, enhance students' comprehension of intricate concepts, such as those in geometry, by including them in demanding activities and conversations (Hassan et al., 2020). Furthermore, research indicates that integrated STEM education can enhance critical thinking, teamwork, and creativity in students, which are vital competencies for success in

the 21st century (Martins, 2024; Fan & Yu, 2015). The incorporation of project-based learning into iSTEM curricula has been shown to improve student engagement and enthusiasm in STEM disciplines, thus mitigating the "leaky pipeline" issue where students withdraw from STEM professions (Loof et al., 2021).

The implementation of iSTEM principles in educational environments is essential for attaining desired results. Hiwatig's research underscores the necessity for a comprehensive comprehension of how many elements of iSTEM might affect student attitudes and involvement, especially concerning demographic variables (Hiwatig, 2024). This indicates that a universal strategy may be ineffective, necessitating customized techniques to address the varied needs of students.

The successful implementation of iSTEM education necessitates a comprehensive strategy encompassing excellent monitoring techniques, substantial teacher professional development, and an emphasis on student participation and outcomes. The current literature establishes a robust basis for comprehending the intricacies of iSTEM education and underscores the necessity for ongoing study and adaptation to enhance pedagogical methods and educational experiences in this vital domain.

Research Methodology

This study employs a bibliometric analysis to examine historical trends, collaboration patterns, and emerging themes in iSTEM research. Data was collected from Scopus, a widely recognized academic database, covering publications from 1985 to 2025. A systematic search strategy was implemented using the keyword “iSTEM” along with related terms such as “Integrated STEM” and “STEM education”. The search focused on titles, abstracts, and keywords to ensure comprehensive coverage of relevant literature. To refine the dataset, only peer-reviewed journal articles and conference papers written in English were included. Publications that did not focus on interdisciplinary STEM integration, as well as non-research documents such as editorials, news articles, and book reviews, were excluded. After applying these criteria and removing duplicate or redundant entries, a total of 88 relevant publications were identified for further analysis.

To explore the research landscape, several bibliometric indicators were examined. The study analyzed publication trends to track the growth of iSTEM research over time, providing insights into the field’s evolution. Additionally, co-authorship networks were mapped to understand collaboration patterns among researchers, revealing influential scholars and institutional partnerships. The impact of different journals was also assessed by examining publication distribution across sources, using metrics such as CiteScore, SCImago Journal Rank (SJR), and Source Normalized Impact per Paper (SNIP). Furthermore, keyword analysis was conducted to identify dominant research themes and emerging topics within iSTEM literature.

To facilitate data visualization, VOSviewer was employed to generate co-authorship networks, keyword clustering maps, and citation analyses. This helped illustrate interdisciplinary connections and research impact across various studies. While the study provides valuable insights, some limitations should be acknowledged. Since the analysis is restricted to Scopus-indexed publications, studies indexed in other databases such as Web of Science or Google Scholar were not included, which may limit the comprehensiveness of the

dataset. Additionally, only English-language publications were considered, potentially excluding relevant studies in other languages. Another limitation is that citation-based metrics, while useful, may not fully capture the quality or real-world impact of the research. Despite these constraints, the findings offer a robust overview of iSTEM research trends and provide a foundation for future studies in this evolving field.

Bibliometric Analysis

To better understand the evolution and impact of iSTEM research, this study employs various bibliometric visualizations, including publication trends, co-authorship networks, journal contributions, and keyword distributions. These visualizations offer valuable insights into the growth of iSTEM literature, collaborative relationships among researchers, and emerging themes in the field.

The annual publication count serves as an indicator of the research field's expansion over time. As depicted in Figure 1, iSTEM-related publications remained relatively low before the early 2000s, with only sporadic increases. However, since 2005, the number of studies has grown significantly, reflecting a rising interest in interdisciplinary STEM education. The publication trend demonstrates a steady increase, with a notable surge between 2020 and 2025. This spike may be attributed to greater policy emphasis on STEM education, increased funding for interdisciplinary research, and technological advancements that facilitate integrated STEM learning.

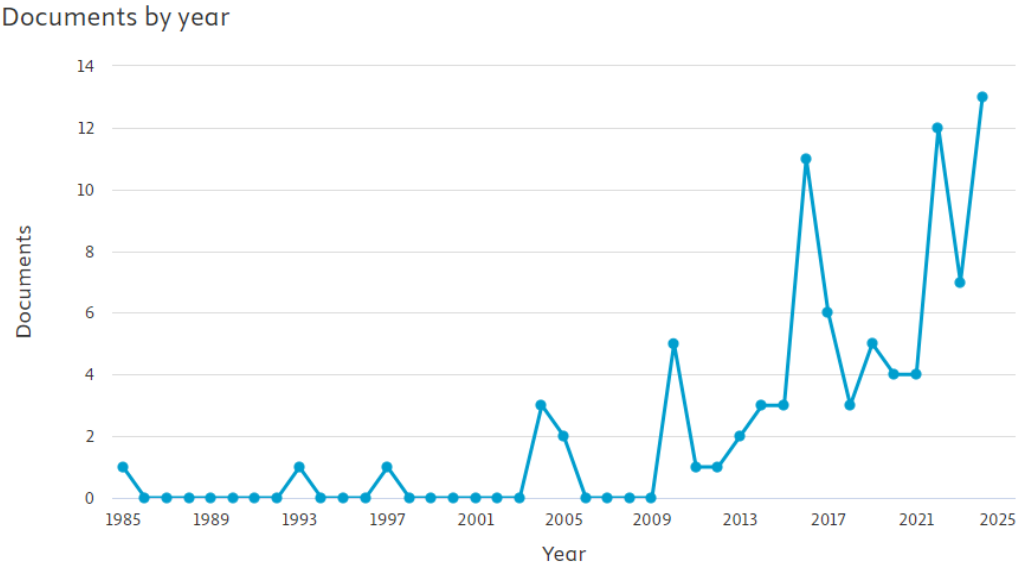

Figure 1 Documents by year

A comparative analysis of publication sources provides insights into the academic venues that have played a pivotal role in disseminating iSTEM research. Figure 2 illustrates the annual publication output from key journals and conferences. The ASEE Annual Conference and Exposition Conference Proceedings consistently contribute a substantial number of publications each year, signifying its importance in STEM education discourse. Journals such as the European Journal of STEM Education have emerged in recent years, highlighting the growing institutional recognition of integrated STEM research. Meanwhile, other journals, including Education Sciences and the International Journal of Science and Mathematics

Education, have made steady contributions, underscoring the interdisciplinary nature of iSTEM scholarship. Fluctuations in publication volumes across different sources suggest shifts in research focus, the emergence of new academic platforms, and variations in funding and policy support.

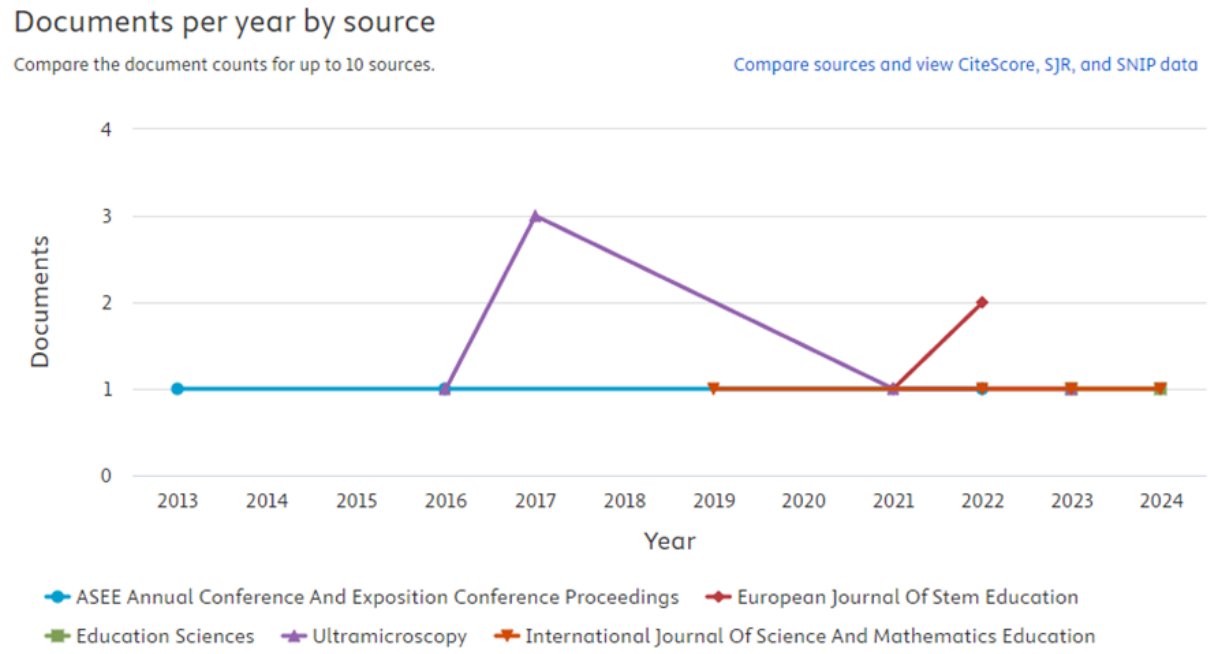

Figure 2 Documents per year by source

Examining authorship trends helps identify influential researchers and collaboration dynamics in the iSTEM field. Figure 3 presents the contributions of leading authors, revealing that a small group of researchers has significantly shaped the discourse on iSTEM education. Scholars such as Krause, Rosenauer, and De Loof have published the highest number of papers, demonstrating their strong influence in the field. Additionally, co-authorship network analysis highlights patterns of collaboration, showing both highly connected research groups and isolated contributors. A dense co-authorship network suggests a well-integrated research community, while the presence of independent authors may indicate niche or specialized areas within iSTEM. Understanding these relationships is crucial for fostering interdisciplinary partnerships and identifying potential opportunities for collaborative research.

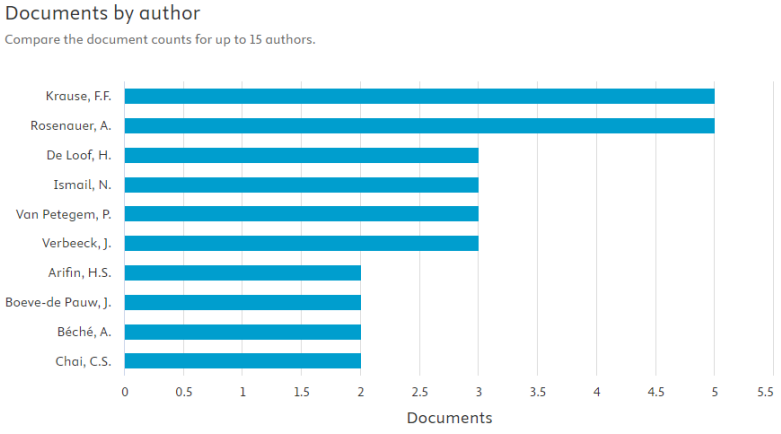

Figure 3 Documents by author

Analyzing the types of documents published provides further insight into how research findings are disseminated. As shown in Figure 4, journal articles constitute the majority of iSTEM publications (68.2%), reflecting the emphasis on peer-reviewed academic discourse. Conference papers account for 18.2%, demonstrating the role of academic conferences in presenting emerging findings and fostering scholarly discussions. The remaining publications include conference reviews (6.8%), book chapters (3.4%), reviews (2.3%), and notes (1.1%), indicating diverse formats of knowledge dissemination in the field. The dominance of journal articles highlights the importance of rigorous, peer-reviewed contributions in shaping iSTEM research, while the significant share of conference papers suggests that researchers actively engage in discussions on evolving methodologies and pedagogical practices.

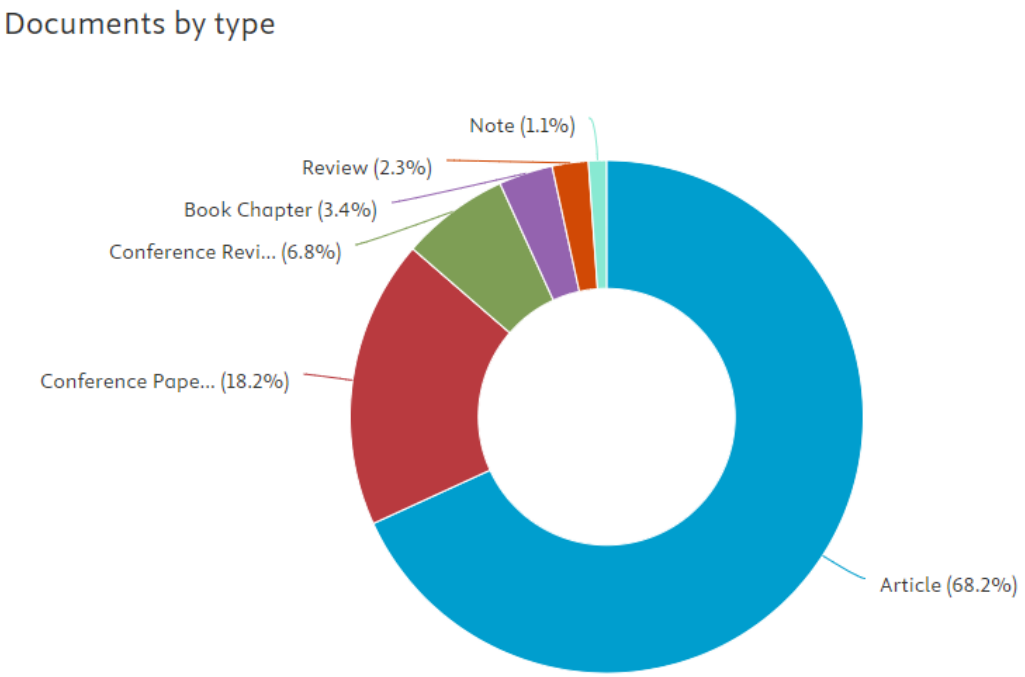

Figure 4 Documents by type

Classifying iSTEM publications by subject area provides insight into the multidisciplinary scope of the field. Figure 5 shows that social sciences account for the largest share of publications (26.5%), emphasizing the educational and pedagogical aspects of iSTEM. Engineering and computer science follow closely, comprising 10.8% and 10.2% of the research output, respectively, indicating a strong focus on technological integration and problem-solving applications. Other contributing disciplines include mathematics (7.8%), physics and astronomy (6.6%), medicine (5.4%), and environmental sciences (3.6%), highlighting the broad application of iSTEM research across various scientific domains. The remaining 16.3% of publications fall into an "Other" category, demonstrating the transdisciplinary nature of iSTEM. The wide distribution of research across multiple fields underscores the importance of cross-disciplinary collaboration in addressing complex real-world challenges.

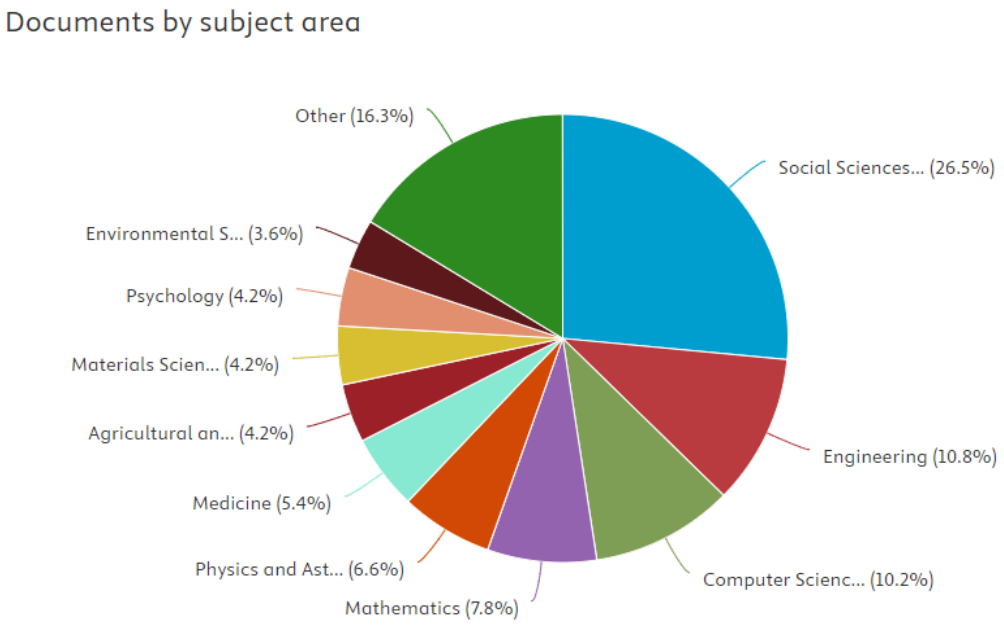

Figure 5 Documents by subject area

Keyword analysis helps identify dominant and emerging themes in iSTEM research. Figure 6 presents a keyword co-occurrence network, visualized using VOSviewer, which categorizes recurring terms into thematic clusters. The red cluster focuses on STEM education, student engagement, and high school curricula, indicating an emphasis on pedagogical aspects. The green cluster highlights controlled studies and human-related research, suggesting methodological approaches in iSTEM evaluation. The blue cluster includes technical terms such as simulation and transmission electron microscopy, reflecting a more experimental and technology-driven research direction. These keyword clusters illustrate the interdisciplinary nature of iSTEM and reveal emerging trends, such as the integration of digital tools and data-driven learning methods.

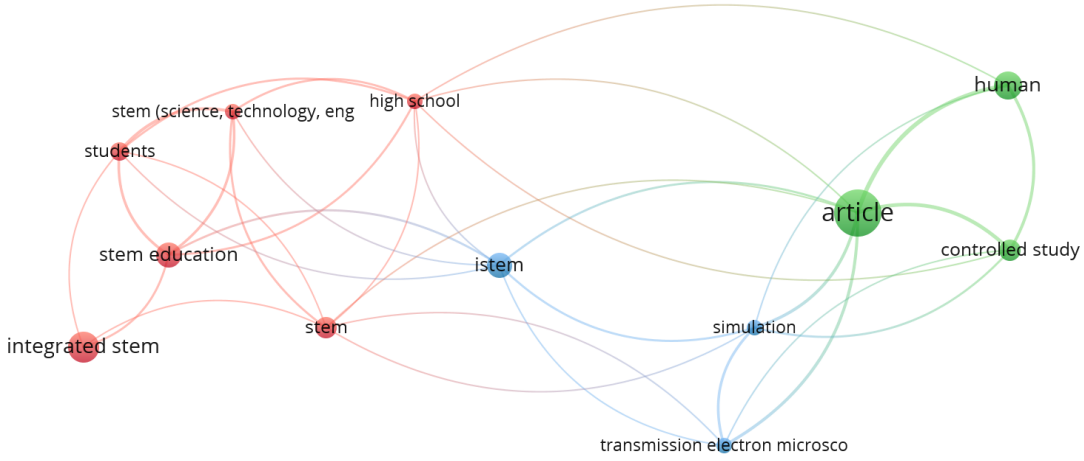

Figure 6 Co-occurrence of keywords

Discussion

The bibliometric analysis of iSTEM research provides significant insights into the field's growth, collaborative patterns, and thematic evolution. Examining the annual publication

trends reveals a substantial increase in iSTEM-related research output over the past two decades. As illustrated in Figure 1, the field experienced slow initial growth before the early 2000s, followed by a steady rise, particularly after 2010. This surge coincides with a global emphasis on STEM education reform, increased funding for interdisciplinary research, and the integration of technology into educational practices. The sharp rise between 2020 and 2025 may be attributed to the growing adoption of digital learning tools, government initiatives supporting STEM education, and heightened research interest in innovative teaching methodologies. However, fluctuations in publication volume suggest that research activity may also be influenced by funding cycles, policy changes, and shifts in academic priorities.

Analyzing publication sources further highlights the role of specific journals and conferences in advancing iSTEM research. Figure 2 shows that the ASEE Annual Conference and Exposition Conference Proceedings has consistently contributed to a significant number of publications, underscoring its importance as a venue for discussing STEM education innovations. The European Journal of STEM Education, which emerged in 2022, demonstrates the increasing institutional recognition of integrated STEM education. Other journals, such as Education Sciences and the International Journal of Science and Mathematics Education, have shown varying publication rates, reflecting shifting research focus areas. The variation in journal impact suggests that while some sources remain consistent in disseminating iSTEM research, new academic platforms are emerging to accommodate evolving research themes.

The authorship and collaboration patterns observed in Figure 3 indicate that iSTEM research is largely shaped by a small group of prolific scholars. Researchers such as Krause, Rosenauer, and De Loof have made significant contributions, while other authors have played more specialized roles. The co-authorship network analysis reveals a mix of highly collaborative groups and independent researchers, suggesting that while interdisciplinary partnerships are prevalent, some areas of iSTEM research remain fragmented. A well-connected co-authorship network enhances knowledge exchange and cross-disciplinary innovation, whereas isolated research clusters may indicate niche studies that require broader collaboration. Strengthening international and inter-institutional research partnerships could further advance the field by integrating diverse perspectives and expertise.

Examining publication types provides insights into how iSTEM research is disseminated. As depicted in Figure 4, the majority of publications are journal articles (68.2%), highlighting the emphasis on rigorous, peer-reviewed research. Conference papers (18.2%) also play a crucial role, suggesting that ongoing discussions at academic conferences contribute to shaping research directions. The presence of conference reviews, book chapters, and review articles indicates the field's engagement in both empirical research and theoretical discourse. The balance between journal and conference publications suggests that iSTEM research benefits from both structured academic inquiry and dynamic discussions in professional gatherings.

The distribution of research across subject areas (Figure 5) further confirms the multidisciplinary nature of iSTEM. The dominance of social sciences (26.5%) underscores the emphasis on educational frameworks, pedagogical strategies, and student engagement. Meanwhile, significant contributions from engineering (10.8%) and computer science (10.2%) suggest an increasing focus on technological integration in STEM education. Other fields, such

as mathematics, physics, medicine, and environmental sciences, contribute to the diverse application of iSTEM research. The broad discipline indicates that iSTEM is not confined to a single domain but rather integrates multiple perspectives to address real-world challenges.

A deeper look into keyword co-occurrence and thematic clusters (Figure 6) reveals key research areas and emerging trends within iSTEM. The red cluster, which includes terms such as STEM education, students, and high school, suggests a strong focus on pedagogical approaches and student engagement strategies. The green cluster, featuring keywords like controlled studies and human-related research, highlights the methodological dimensions of iSTEM education, particularly in assessing learning outcomes. The blue cluster, which includes terms like simulation and transmission electron microscopy, reflects a more technical and experimental aspect of iSTEM research, emphasizing its application in engineering and physical sciences. The interconnectedness of these clusters reinforces the interdisciplinary nature of iSTEM and suggests that future research should continue to bridge gaps between educational theory, technological advancements, and empirical assessments of learning impact.

Conclusions

This bibliometric analysis of iSTEM research highlights significant growth in interdisciplinary STEM education over the past two decades. The findings reveal an increasing academic interest, with substantial contributions from social sciences, engineering, and computer science. The co-authorship analysis indicates a highly collaborative research landscape, fostering interdisciplinary partnerships across institutions and geographical boundaries. Keyword analysis further suggests that iSTEM research is evolving toward emerging themes, including technology integration, pedagogical innovations, and computational tools in STEM learning.

Despite this progress, certain challenges remain. A key research gap is the lack of longitudinal studies on the long-term impact of iSTEM education on student learning outcomes and career trajectories. Future research should investigate how integrated STEM education influences problem-solving skills, workforce readiness, and academic performance over time. Additionally, further studies are needed to evaluate the effectiveness of teacher training programs, ensuring that educators are well-equipped to implement iSTEM methodologies in diverse educational settings.

Technological advancements, such as artificial intelligence, virtual reality, and adaptive learning platforms, offer promising directions for enhancing STEM education. Future research should explore AI-driven personalized learning, immersive simulations, and gamification techniques to improve student engagement. Moreover, given the increasing global emphasis on sustainability, integrating environmental and sustainability principles into iSTEM curricula could better prepare students to address pressing global challenges.

From a policy perspective, expanding bibliometric studies to analyze how government policies, funding mechanisms, and international collaborations influence iSTEM research would be valuable. A comparative analysis of global iSTEM education policies could identify best practices and areas for improvement. Additionally, broadening the scope of bibliometric

analyses to include multiple academic databases, such as Web of Science and IEEE Xplore, could provide a more comprehensive overview of research trends.

In conclusion, this study serves as a foundation for researchers, educators, and policymakers seeking to understand the evolution of iSTEM research. By addressing existing research gaps, leveraging technological advancements, and developing evidence-based policies, future studies can further strengthen iSTEM's role in shaping the next generation of scientists, engineers, and educators.

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