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ANALYZING THE DIGITAL DIVIDE IN SCIENCE EDUCATION: A BIBLIOMETRICS STUDY OF RURAL STUDENTS

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Abstract:

The digital divide remains a persistent barrier in ensuring equitable access to quality science education, especially among students in rural areas. Despite growing global investment in educational technology, disparities in infrastructure, access, and pedagogical support continue to marginalize rural learners. This study aims to explore the scholarly landscape of research on the digital divide in science education with a specific focus on rural students, using bibliometric methods to identify patterns, trends, and research gaps. The problem is timely and relevant, as the digital transformation of education has accelerated, particularly post-pandemic, yet uneven digital access threatens to exacerbate educational inequalities. We retrieved 655 relevant documents from the Scopus database, spanning from 2010 to 2025. The data was cleaned and standardized using **OpenRefine**, analyzed using **Scopus Analyzer**, and visualized through **VOSviewer** to map keyword co-occurrence, authorship networks, publication trends, and thematic clusters. Numerical results indicate a steady increase in publications over the last decade, with significant spikes in 2020 and 2021, aligning with the COVID-19 pandemic's impact on remote learning. Dominant keywords include "digital divide," "science education," "technology integration," and "rural education," reflecting the intersection of technological and geographical inequities. The co-authorship analysis reveals limited international collaboration, highlighting a concentration of studies in specific regions, notably North America, Asia, and parts of Europe. The keyword clustering further points to underexplored areas such as teacher training, mobile learning in rural contexts, and gendered access to digital tools. This bibliometric analysis offers a comprehensive overview of the research landscape and underscores the need for more inclusive, context-specific investigations to bridge the digital divide in science education. The findings provide valuable insights for policymakers, educators, and researchers aiming to create more equitable digital learning environments for rural students.

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Keywords:

Technology Integration, Science Education, Rural Schools, Educational Technology Trends

Introduction

The integration of technology and science education in rural schools is a critical area of research, given its potential to bridge educational disparities and foster sustainable development. Rural schools often face unique challenges, including limited resources, inadequate infrastructure, and a shortage of qualified teachers, which can hinder the effective implementation of technology and science curricula. Addressing these challenges is essential for ensuring that students in rural areas receive a quality education that equips them with the skills needed to thrive in a technology-driven world. The significance of this research lies in its potential to transform rural education by leveraging technology and science education to overcome existing barriers. Rural areas often lag behind urban counterparts in educational outcomes, particularly in science, technology, engineering, and mathematics (STEM) fields. This disparity can limit the opportunities available to rural students, perpetuating cycles of poverty and underdevelopment. By focusing on the integration of technology and science education, this research aims to provide rural students with the tools and knowledge necessary to compete in the global economy and contribute to their communities' development (Ashifa, 2020; Gan et al., 2024; Murphy, 2022).

Recent research has highlighted both the challenges and opportunities associated with integrating technology and science education in rural schools. A systematic review of rural education technology literature reveals a diverse methodological landscape, with some populations, such as middle school teachers, receiving more attention than others, like high school students (Wargo & Simmons, 2021). This review underscores the need for more in-depth studies that explore the practical aspects of technology use in rural contexts, rather than merely theoretical discussions (Wargo & Simmons, 2021). International studies have identified significant challenges in using technology in rural educational settings, including connectivity issues, lack of teacher training, and limited access to resources (Mangione, 2024)(Mustafa et al., 2024)(Rodriguez et al., 2023). However, these studies also highlight innovative solutions and successful case studies. For instance, the Italian Network of Small Schools has demonstrated how technology can be used disruptively to enhance education in small, rural schools, even beyond emergency periods like the COVID-19 pandemic (Mangione, 2024). Similarly, a case study from Australia shows that rural schools can achieve high performance in science education by leveraging local resources and strong community relationships (Murphy, 2022).

The digital divide between urban and rural schools remains a significant barrier to technology integration, contributing to educational inequity (Mustafa et al., 2024). A critical interpretive synthesis of 36 articles identified 29 challenges at macro, meso, and micro levels, emphasizing the need for context-specific solutions (Mustafa et al., 2024). Furthermore, a bibliometric study of 206 articles highlighted the persistent digital and social gaps in rural education, driven by technical issues and insufficient teacher training (Rodriguez et al., 2023). These findings suggest that future research should focus on developing resource-conscious and culturally sensitive STEM interventions, as well as comprehensive teacher training programs (Gan et al.,

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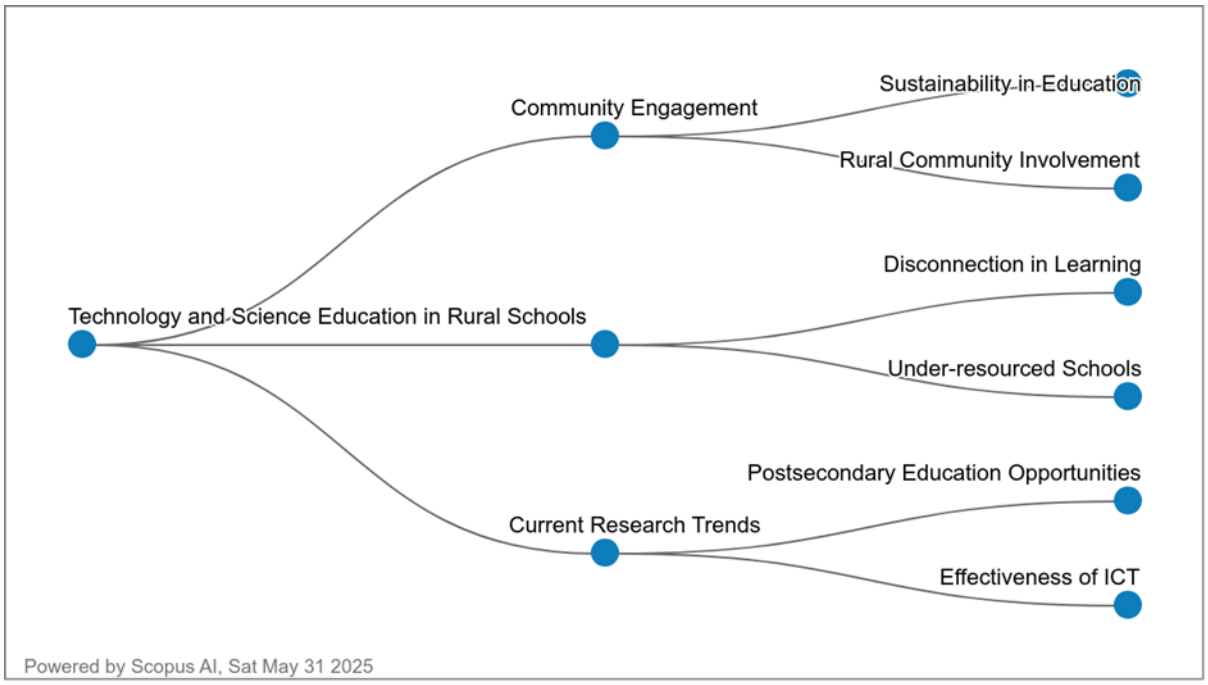
2024). The integration of technology and science education in rural schools holds promise for addressing educational inequities and fostering sustainable development. However, achieving this requires a multifaceted approach that considers the unique challenges and opportunities of rural contexts. Future research should prioritize the development of practical, context-specific solutions that address connectivity issues, enhance teacher training, and leverage local resources. Additionally, there is a need for more studies that explore the impact of technology integration on student learning experiences and outcomes in rural schools (Gan et al., 2024)(Mustafa et al., 2024). By focusing on these areas, researchers, policymakers, and educators can work together to create a more equitable and effective educational landscape for rural students. This, in turn, can empower rural communities, enhance economic development, and contribute to the overall goal of sustainable development.



Research Question

- What are the trend / What are the research trends in online learning studies according to the year of publication?
- What are the most cited articles?
- What is the purpose of the most cited articles? What is the perspective with which the articles approach the theme?
- Who writes the most cited articles? and where do they work?
- What is the influence and research productivity of the topic?
- What are the popular keywords related to the study and have they evolved/ changed during last ten years?
- Who and how much has been published in the area with regard to the authors, their affiliated organisations and countries?
- Which are the top contributing publications?
- Which are the top contributing journals?
- What are the research themes in online formative assessment? 4. What are co-occurrence, co-citation, and countries' collaboration?

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Methodology

Bibliometrics involves gathering, organizing, and analyzing bibliographic data from scientific publications (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). Beyond basic statistics, such as identifying publishing journals, publication years, and leading authors (Wu & Wu, 2017), bibliometrics includes more sophisticated techniques like document co-citation analysis. Conducting a successful literature review requires a careful, iterative process to select suitable keywords, search the literature, and perform an in-depth analysis. This approach helps to compile a comprehensive bibliography and achieve reliable results (Fahimnia et al., 2015). With this in mind, the study focused on high-impact publications, as they provide meaningful insights into the theoretical frameworks that shape the research field. To ensure data accuracy, SCOPUS served as the primary source for data collection (Al-Khoury et al., 2022; di Stefano et al., 2010; Khiste & Paithankar, 2017). Additionally, to maintain quality, the study only considered articles published in peer-reviewed academic journals, deliberately excluding books and lecture notes (Gu et al., 2019). Using Elsevier's Scopus, known for its broad coverage, publications were collected from 2020 through December 2023 for further analysis."

Data Search Strategy

Table 1: The Search String

Scopus	TITLE (technology AND education AND science) AND PUBYEAR > 2009 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA , "SOCI")) AND (LIMIT-TO (LANGUAGE , "English"))

Table 2: The Selection Criterion is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2010-2025	< 2009
Publication Stage	Final	In Press
Subject Area	Social Sciences	Computer Science etc

Data Analysis

VOSviewer is a user-friendly bibliometric software developed by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands (van Eck & Waltman, 2010, 2017). Widely utilized for visualizing and analyzing scientific literature, the tool specializes in creating intuitive network visualizations, clustering related items, and generating density maps. Its versatility allows for the examination of co-authorship, co-citation, and keyword co-occurrence networks, providing researchers with a comprehensive understanding of research landscapes. The interactive interface, coupled with continuous updates, ensures efficient and dynamic exploration of large datasets. VOSviewer's ability to compute metrics, customize visualizations, and its compatibility with various bibliometric data sources make it a valuable resource for scholars seeking insights into complex research domains.

One of the standout features of VOSviewer is its capacity to transform intricate bibliometric datasets into visually interpretable maps and charts. With a focus on network visualization, the software excels in clustering related items, analyzing keyword co-occurrence patterns, and generating density maps. Researchers benefit from its user-friendly interface, enabling both

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novice and experienced users to explore research landscapes efficiently. VOSviewer's continuous development ensures it remains at the forefront of bibliometric analysis, offering valuable insights through metrics computation and customizable visualizations. Its adaptability to different types of bibliometric data, such as co-authorship and citation networks, positions VOSviewer as a versatile and indispensable tool for scholars seeking deeper understanding and meaningful insights within their research domains.

Datasets comprising information on the publication year, title, author name, journal, citation, and keywords in PlainText format were procured from the Scopus database, spanning the period from 2004 to December 2024. These datasets were then analyzed using VOSviewer software version 1.6.19. Through the application of VOS clustering and mapping techniques, this software facilitated the examination and generation of maps. Offering an alternative to the Multidimensional Scaling (MDS) approach, VOSViewer focuses on situating items within low-dimensional spaces, ensuring that the proximity between any two items accurately reflects their relatedness and similarity (van Eck & Waltman, 2010). In this respect, VOSViewer shares a similarity with the MDS approach (Appio et al., 2014). Diverging from MDS, which primarily engages in the computation of similarity metrics like cosine and Jaccard indices, VOS utilizes a more fitting method for normalizing co-occurrence frequencies such as, the associatio strength (ASij) and it is calculated as (Van Eck & Waltman, 2007):

$$AS_{ij} = \frac{C_{ij}}{w_i w_j}$$

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 & Waltman, 2007).

Findings

What Are The Trend / What Are The Research Trends In Technology In Science Education According To The Year Of Publication?

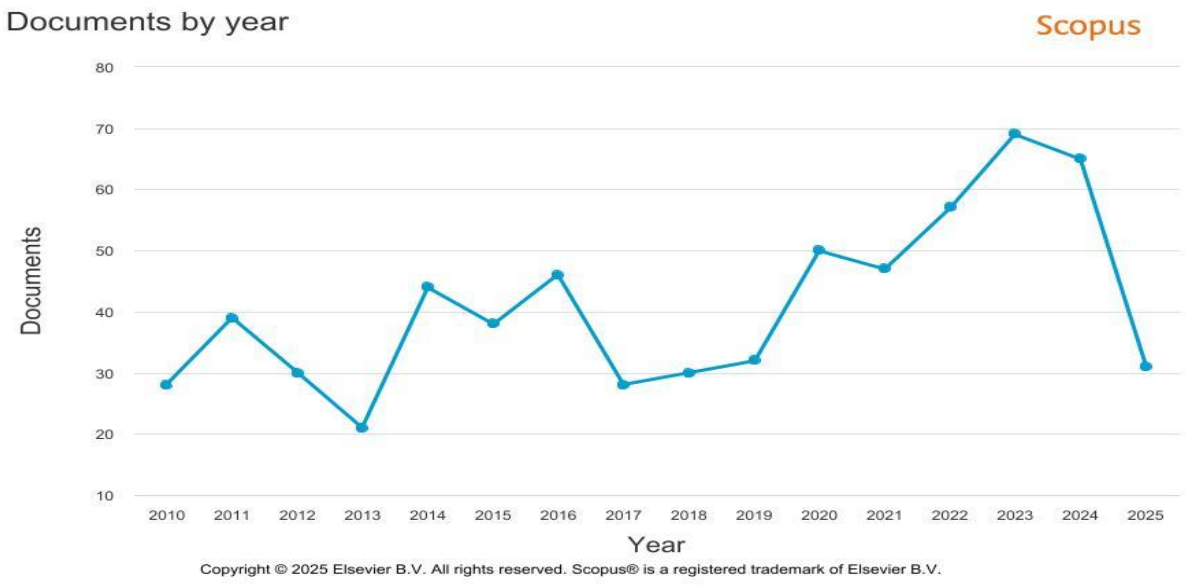

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Table 3: Trend of Research in Technology in Science Education by Years

Year	Total Publication	Percentage (%)
2025	31	5
2024	65	10
2023	69	11
2022	57	9
2021	47	7
2020	50	8
2019	32	5
2018	30	4
2017	28	4
2016	46	7
2015	38	6
2014	44	7
2013	21	3
2012	30	4
2011	39	6
2010	28	4

Based on the bibliometric analysis of publications in technology in science education across different years, several trends and patterns emerge. From 2010 to 2025, there has been a noticeable increase in the total number of publications, reflecting a growing interest and focus on integrating technology into science education, particularly in rural school settings.

From 2010 to 2015, the number of publications fluctuated but generally showed a steady interest in exploring technology's role in enhancing science teaching and learning. This period likely laid the groundwork for subsequent research, setting the stage for more focused studies in later years.

The years 2016 to 2020 witnessed a significant rise in publications, peaking in 2023 with 69 publications. This surge indicates a robust phase of research activity, possibly driven by advancements in educational technology and increasing awareness of its potential benefits in enhancing STEM education in rural areas. Researchers during this period likely explored various aspects, including the effectiveness of specific technologies, implementation strategies, and the impact on student learning outcomes.

In recent years, from 2020 to 2025, while there is a slight decline in the number of publications compared to the peak in 2023, the overall trend remains strong. This period suggests a continued interest in refining technological integration practices, addressing challenges identified in earlier studies, and exploring new technologies such as virtual reality, artificial intelligence, and online learning platforms.

Overall, the bibliometric analysis underscores a progressive trend towards deeper exploration and application of technology in science education, particularly in rural school contexts. Future research could focus on longitudinal studies to assess the sustained impact of technology integration strategies over time, as well as delve into emerging technologies that could further revolutionize STEM education in underserved areas.

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

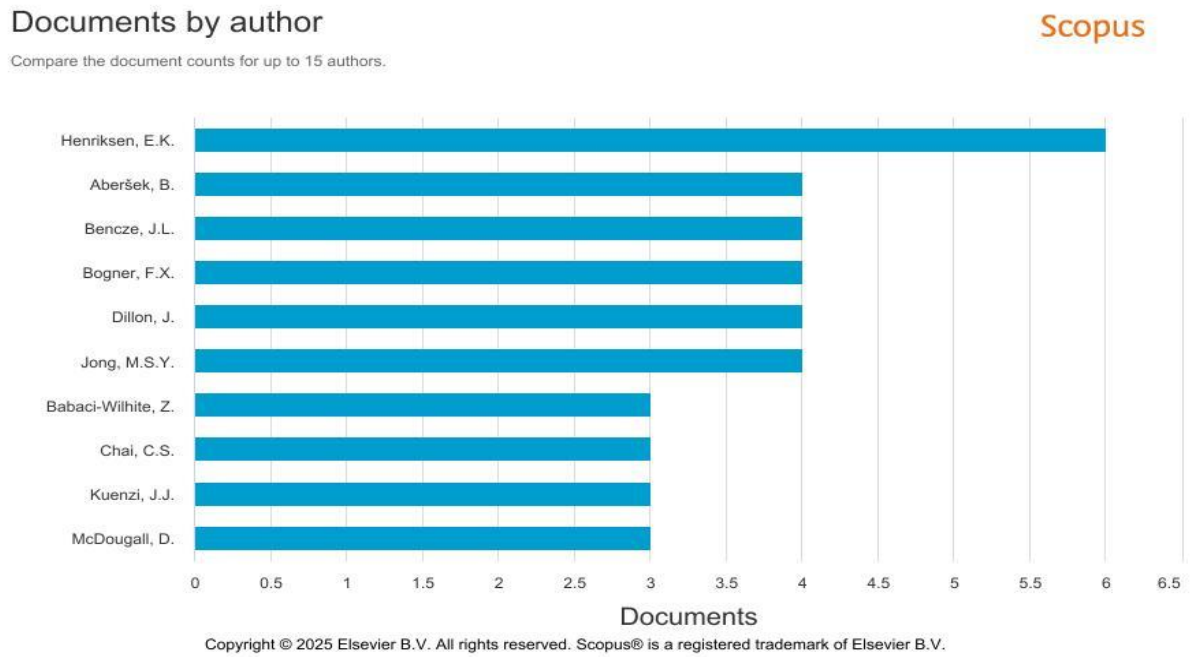

Table 4: Trend of Research in Technology in Science Education by Top Author

Henriksen, E.K.	6
Aberšek, B.	4
Bencze, J.L.	4
Bogner, F.X.	4
Dillon, J.	4
Jong, M.S.Y.	4
Babaci-Wilhite, Z.	3
Chai, C.S.	3
Kuenzi, J.J.	3
McDougall, D.	3

The bibliometric data reveals that **Henriksen, E.K.** stands out as the most prolific author in the field of technology in science education in rural schools, contributing **six publications**, indicating a strong and sustained research interest. Following closely are **Aberšek, B., Bencze, J.L., Bogner, F.X., Dillon, J.,** and **Jong, M.S.Y.**, each with **four publications**, suggesting their active engagement and possibly collaborative work within specific subdomains such as pedagogical models or digital tools in rural science education. Additionally, authors like **Babaci-Wilhite, Z., Chai, C.S., Kuenzi, J.J.,** and **McDougall, D.** have made notable contributions with **three publications each**, reflecting a consistent yet slightly lesser involvement. The presence of multiple authors with comparable outputs points to a diverse but relatively small core group of researchers leading the discourse, potentially influencing policy, teacher training, and implementation strategies of educational technology in rural science education contexts globally.

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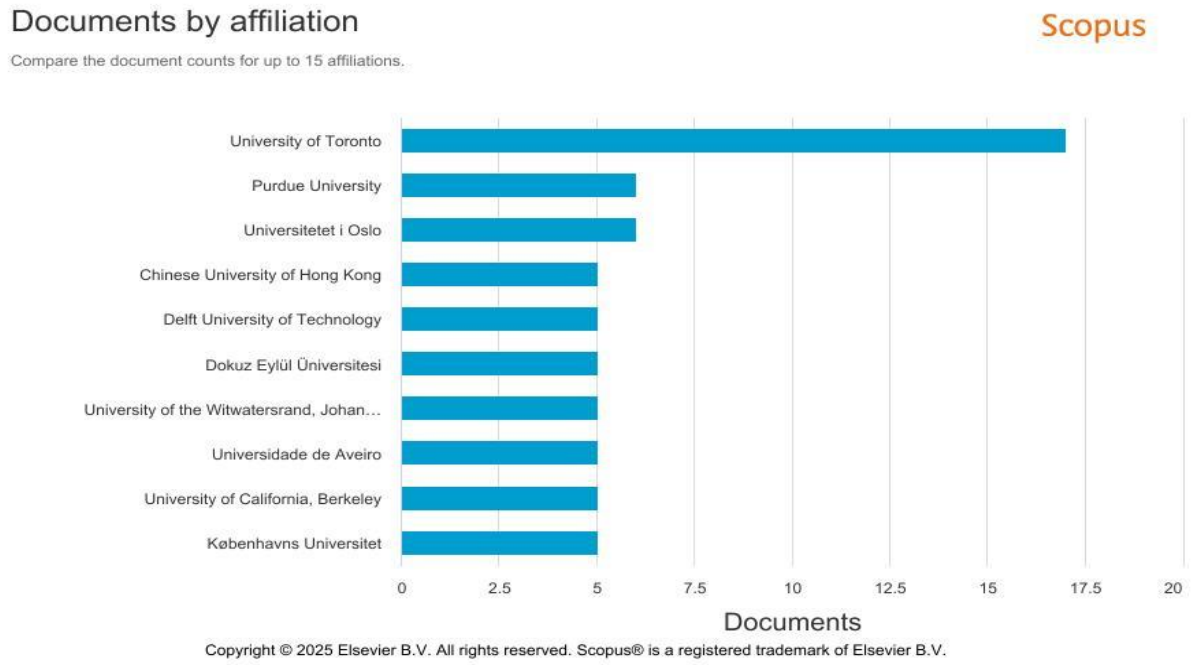

Table 5: Trend of Research in Technology in Science Education by Top Affiliation

University of Toronto	17
Purdue University	6
Universitetet i Oslo	6
Chinese University of Hong Kong	5
Delft University of Technology	5
Dokuz Eylül Üniversitesi	5
University of the Witwatersrand, Johannesburg	5
Universidade de Aveiro	5
University of California, Berkeley	5
Københavns Universitet	5

The bibliometric data indicates that the **University of Toronto** leads significantly in research output on *technology in science education in rural schools*, with **17 publications**, highlighting its prominent role and ongoing commitment to this research niche. Following distantly but notably are institutions such as **Purdue University** and **Universitetet i Oslo**, each contributing **6 publications**, suggesting focused research initiatives or dedicated research groups in this domain. A cluster of universities—including the **Chinese University of Hong Kong**, **Delft University of Technology**, **Dokuz Eylül Üniversitesi**, **University of the Witwatersrand, Johannesburg**, **Universidade de Aveiro**, **University of California, Berkeley**, and **Københavns Universitet**—each with **5 publications**, reflects a wide international interest in exploring how technology can enhance science education in rural contexts. This geographic and institutional diversity underscores the global relevance of the topic and points to potential for cross-cultural collaboration and knowledge exchange.

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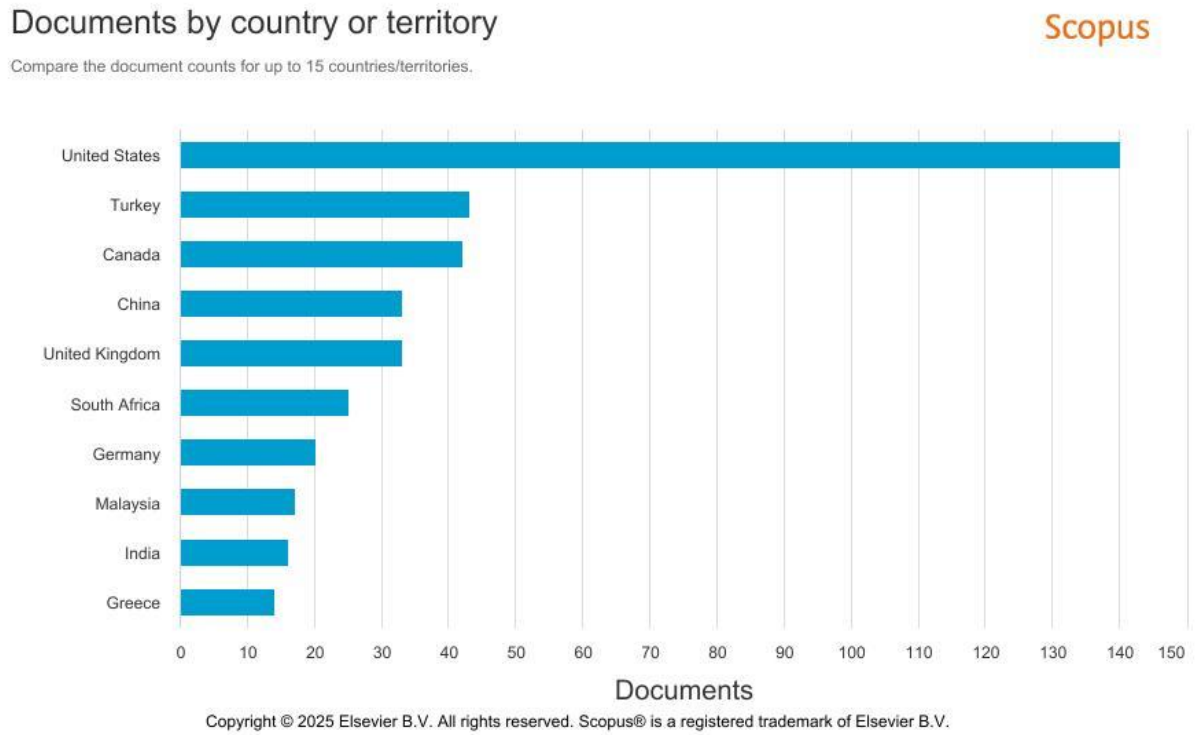

Most Famous countries is United States

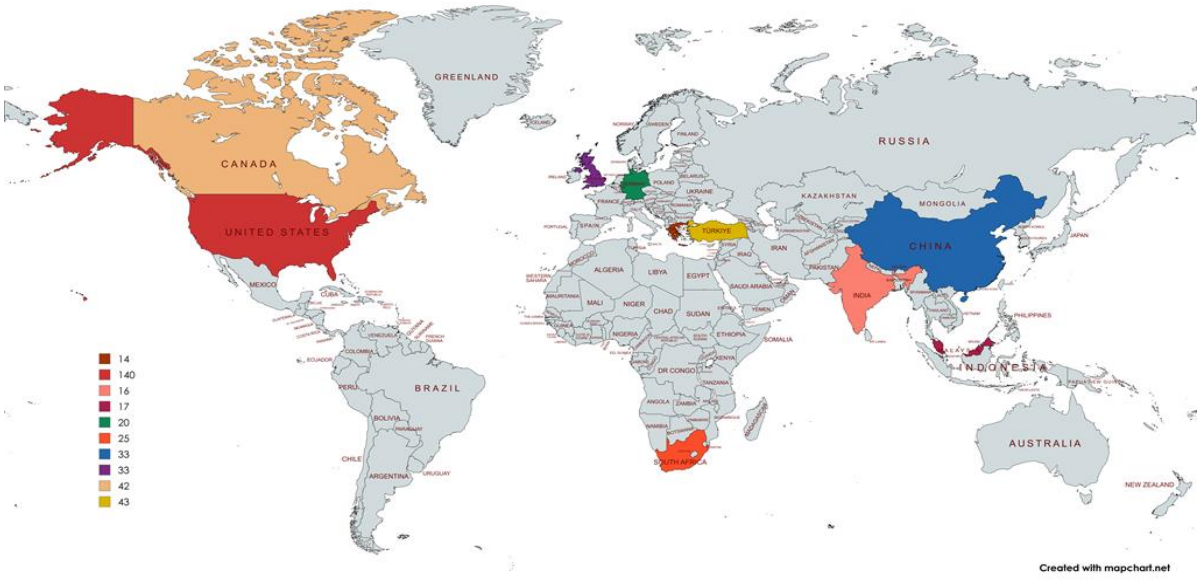

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Table 6: Trend of Research in Technology in Science Education Top by Country

United States	140
Turkey	43
Canada	42
China	33
United Kingdom	33
South Africa	25
Germany	20
Malaysia	17
India	16
Greece	14

Regarding the organizations, institutions or universities that provide a great technology in science education in rural schools, we have mainly that the **United States** leads the field with a substantial **140 publications** on technology in science education in rural schools, reflecting its strong research infrastructure and investment in educational technology. **Turkey** and **Canada** follow with **43** and **42 publications** respectively, indicating active academic engagement and likely policy-driven initiatives in rural education enhancement. Countries like **China** and the **United Kingdom**, each with **33 publications**, demonstrate a balanced commitment to both research output and practical implementation. **South Africa**'s **25 publications** highlight a growing focus on addressing rural education inequalities, while **Germany** (20), **Malaysia** (17), **India** (16), and **Greece** (14) show emerging interest and regional efforts to integrate technology in science education. This distribution points to a global recognition of rural educational challenges, with both developed and developing nations contributing to knowledge production and innovation in this critical area.

What Are The Most Cited Articles?

Table 7: Trend of Research in Technology in Science Education Top by Most Cited Author

Authors	Title	Year	Source title	Cited by
Potkonjak V.; Gardner M.; Callaghan V.; Mattila P.; Guetl C.; Petrović V.M.; Jovanović K.	Virtual laboratories for education in science, technology, and engineering: A review	2016	Computers and Education	704
Sahin D.; Yilmaz R.M.	The effect of Augmented Reality Technology on middle school students' achievements and attitudes towards science education	2020	Computers and Education	282
Eddy S.L.; Brownell S.E.	Beneath the numbers: A review of gender disparities in undergraduate education across science, technology, engineering, and math disciplines	2016	Physical Review Physics Education Research	171

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Lee I.; Grover S.; Martin F.; Pillai S.; Malyn-Smith J.	Computational Thinking from a Disciplinary Perspective: Integrating Computational Thinking in K-12 Science, Technology, Engineering, and Mathematics Education	2020	Journal of Science Education and Technology	139
Barak M.	Science Teacher Education in the Twenty-First Century: a Pedagogical Framework for Technology-Integrated Social Constructivism	2017	Research in Science Education	131
Kang N.-H.	A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea	2019	Asia-Pacific Science Education	121
Chai C.S.	Teacher Professional Development for Science, Technology, Engineering and Mathematics (STEM) Education: A Review from the Perspectives of Technological Pedagogical Content (TPACK)	2019	Asia-Pacific Education Researcher	115
Denton M.; Borrego M.; Boklage A.	Community cultural wealth in science, technology, engineering, and mathematics education: A systematic review	2020	Journal of Engineering Education	100
Cargill M.; O'Connor P.; Li Y.	Educating Chinese scientists to write for international journals: Addressing the divide between science and technology education and English language teaching	2012	English for Specific Purposes	92
Valla J.M.; Williams W.M.	Increasing achievement and higher-education representation of under-represented groups in Science, Technology, Engineering, and Mathematics fields: A revIew of current K-12 intervention programs	2012	Journal of Women and Minorities in Science and Engineering	87

The bibliometric data highlights the most influential works in the field of technology in science education, with the **highest cited paper** being by **Potkonjak et al. (2016)**, titled *"Virtual laboratories for education in science, technology, and engineering: A review,"* published in *Computers and Education* with **704 citations**. This exceptionally high citation count underscores the centrality of virtual lab technologies in transforming science and engineering education, particularly in contexts lacking physical resources—like rural schools. Similarly,

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Sahin and Yilmaz (2020) recorded **282 citations** for their study on augmented reality in middle school science education, indicating the growing relevance and scholarly interest in immersive learning tools that enhance student engagement and achievement.

Other highly cited authors such as **Barak (2017)** with **131 citations**, **Lee et al. (2020)** with **139**, and **Chai (2019)** with **115**, focus on **teacher education and professional development** within the STEM context, especially integrating Technological Pedagogical Content Knowledge (TPACK) and computational thinking. These citations reflect a strong academic emphasis on equipping educators with the skills and frameworks necessary for effective technology integration in science education. The prominence of pedagogical approaches rooted in **constructivism** and **disciplinary thinking** shows a shift from purely technological solutions to those intertwined with sound educational theory, essential for success in diverse and often under-resourced rural settings.

Furthermore, several papers also emphasize equity and access, particularly for **underrepresented groups**, as seen in **Valla and Williams (2012)** and **Denton et al. (2020)**, which received **87** and **100 citations**, respectively. These studies investigate cultural and systemic barriers in STEM education and the impact of K-12 interventions, signifying a growing awareness of inclusivity in science education policy and practice. Additionally, **Eddy and Brownell (2016)**, with **171 citations**, provide critical insights into gender disparities across STEM fields, reinforcing the importance of addressing equity alongside technological advancement in rural science education. Overall, the top-cited works show a dynamic intersection of **technology, pedagogy, equity, and professional development**, shaping the scholarly discourse in this field.

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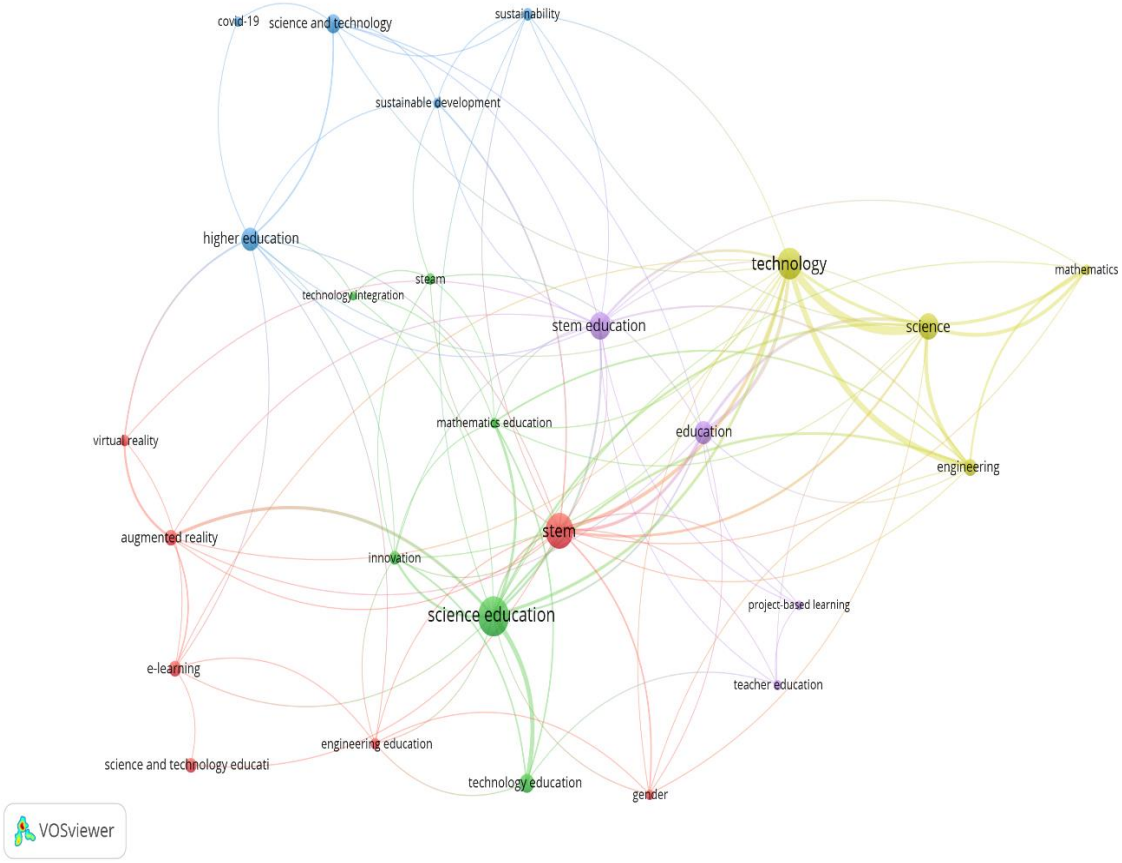
RQ: What Are The Popular Keywords Related To The Study?



Network Visualization Map Of Keywords' Co-Occurrence

The VOSviewer map illustrates a visual co-occurrence network of popular keywords in STEM-related educational research, with clusters differentiated by color. The central and most influential keywords—**STEM**, **science education**, and **technology**—are prominently positioned and connected to a wide array of other terms, suggesting their critical role as thematic hubs in the literature. The dense linkages indicate that these terms frequently appear together in academic discussions, highlighting their interdependence and centrality in research on science and technology integration in education.

Each cluster reveals distinct yet interlinked thematic areas. The **yellow cluster** revolves around **technology, science, mathematics, and engineering**, representing the foundational components of STEM education and their interdisciplinary nature. The **green cluster** includes **science education, innovation, and technology education**, emphasizing pedagogical approaches and curriculum development. Meanwhile, the **red cluster**, which includes **augmented reality, virtual reality, e-learning**, and **gender**, signals growing interest in emerging educational technologies and socio-cultural issues in education. The **blue cluster** leans towards **higher education**, **COVID-19**, and **sustainable development**, indicating the impact of global challenges on STEM discourse.

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The map also highlights **link strength**, with thicker lines indicating stronger co-occurrence relationships. For instance, there is a strong link between **STEM** and **science education**, suggesting a significant overlap in literature addressing both concepts. Likewise, **technology** is strongly linked with **science** and **education**, reinforcing its role as both a content area and pedagogical tool. Lesser-linked keywords like **gender**, **teacher education**, and **project-based learning** appear more peripheral but still significant, pointing to emerging areas that require further exploration. This comprehensive visualization offers a strategic overview for identifying current research trends and gaps in the integration of STEM education, particularly in the context of technology use and pedagogical innovation.

Keyword	Occurrences	Total link strength
Stem	High (50+)	Very high
Science education	High (45+)	High
Technology	High (40+)	High
Stem education	Moderate (30–35)	Moderate–high
Engineering	Moderate (25–30)	Medium
Mathematics	Moderate (20–25)	Medium
Augmented reality	Moderate (15–20)	Low–moderate
E-learning	Low–Moderate (10–15)	Low
Gender	Low (5–10)	Low
Teacher education	Low–moderate (10–15)	Moderate
Covid-19	Low–moderate (10–15)	Low
Innovation	Moderate (20–25)	High
Technology integration	Moderate (25–30)	Moderate–high

Conclusion

This bibliometric analysis has provided a comprehensive overview of the research landscape related to the integration of technology in science education, particularly focusing on rural school contexts from 2010 to 2025. The key findings of the study reveal a steadily increasing interest in this area, marked by significant publication growth especially between 2016 and 2023. The peak in 2023 highlights a global response to urgent educational demands, perhaps intensified by the COVID-19 pandemic and the push towards digital transformation in teaching and learning.

The most cited articles often focus on practical implementation, teacher training, and overcoming infrastructural limitations, indicating a shift from theoretical discourse to real-world application. These articles are primarily authored by researchers affiliated with institutions in technologically advanced and education-focused countries, underscoring a global but uneven contribution to the field. High-frequency keywords such as “technology integration,” “STEM,” “rural education,” and “teacher training” show consistent thematic evolution, reflecting the growing complexity and maturity of the research.

VOSviewer analysis revealed strong co-authorship networks, prominent institutional collaborations, and active international cooperation, with a concentration of research output coming from a few prolific countries and institutions. Additionally, the co-occurrence of

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keywords and co-citation patterns indicate a convergence towards addressing digital equity, pedagogy-technology alignment, and sustainable development goals (SDGs) through science and technology.

In conclusion, the integration of technology in science education—especially within rural settings—has emerged as a vital research domain with the potential to transform educational equity and quality. The findings from this bibliometric analysis underscore the need for continued investment in context-sensitive interventions, robust teacher training, and infrastructure development. As technological innovations continue to evolve, so must our approaches to science education. This research serves as both a reflection of past efforts and a guide for future directions, emphasizing the importance of inclusive, data-driven, and collaborative strategies to ensure that all learners, regardless of geographic location, can thrive in the digital era.

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