

Analysis of Research Evolution and Dissemination on Subject Areas and Global Research Collaboration on Distance and Online Learning in STEM Education Based on Bibliometrics

Aslizah Mohd-Aris^{1*}, Norwati Roslim², Aslinda Mohd-Aris³, Roni Pazla⁴

¹School of Biology, Faculty of Applied Sciences, Universiti Teknologi MARA, Cawangan Negeri Sembilan, Kampus Kuala Pilah, 72000 Kuala Pilah, Negeri Sembilan, Malaysia,

²Academy of Language Studies, Universiti Teknologi MARA, Cawangan Negeri Sembilan, Kampus Rembau, 71300 Rembau, Negeri Sembilan, Malaysia, ³Bahagian Perancangan dan Penyelidikan Dasar Pendidikan, Kementerian Pendidikan Malaysia, 62604 Wilayah Persekutuan Putrajaya, Malaysia, ⁴Department of Animal Nutrition and Feed Technology, Faculty of Animal Science, Universitas Andalas, Padang, West Sumatra, Indonesia

Corresponding Author Email: aslizah@uitm.edu.my*

To Link this Article: <http://dx.doi.org/10.6007/IJARPED/v14-i2/25308> DOI:10.6007/IJARPED/v14-i2/25308

Published Online: 04 May 2025

Abstract

This study aims to conduct a comprehensive review and bibliometric analysis of a reliable database of data on distance and online learning in STEM education. The main objectives of this paper were to determine the prevailing research focus on distance and online learning in STEM education. This research categorised and assessed data from 648 academic articles related to distance and online learning in STEM education using bibliometric methods. VOSviewer was used to graphically visualise the data. The results of the study show that the development and dissemination of research in STEM education began as early as 1996, with a significant increase in 2011 and a peak in publications in 2021. The critical topic areas are centred on multidisciplinary areas, regardless of STEM discipline. It was found that research collaboration can point to far-reaching problems around the world. The findings of this article are a valuable addition to systematic literature reviews and meta-analyses on distance and online learning in STEM education. The study strongly encourages further research into the impact of distance and online learning in STEM education, particularly comparing uptake rates in rural and urban areas and gender preferences for STEM education using both learning methods.

Keywords: Bibliometric, Distance Learning, Online Learning, STEM Education, VOSViewer

Introduction

Recently, STEM education research has gained increasing scientific attention. STEM education research provides researchers with practical knowledge, particularly in the areas

of science, technology, engineering, and maths education pedagogy, by examining STEM education research. The emergence of STEM (Science, Technology, Engineering, and Mathematics) is attributed to the increasing demand for science and technology education driven by the continuous advancement of technology and the increasing digitalisation of society. However, given the significant increase in demand for STEM education and to support its use in the field, researchers could investigate the significant research gap to create a sustainable framework for STEM education.

In this study, a bibliometric analysis was conducted of papers published on a topic related to distance and online learning in STEM education research. This paper primarily addresses the following research areas to identify the bibliometric indicators:

RQ1: How advanced is the development and diffusion of distance and online learning within STEM education research?

RQ2: What are the critical areas of research related to distance and online learning in STEM education?

RQ3: How can the key players in STEM education research related to distance and online learning be identified?

This study was done because findings from this type of research analysis is important to guide future research in the right direction. Thus, in future, the influential researchers able to explore more potential applications of STEM education, and significantly creating the knowledge base for STEM education research.

Literature Review

As Cai et al. (2023) found, the number of publications and citations in STEM education is increasing exponentially every year. Furthermore, Ali and Tse (2023) have shown that the use of bibliometric data to identify publications and authors, with a particular focus on the emergent approach in STEM education, has led to a significant citation impact. Pearson (2017) has shown that integrated STEM education helps students develop 21st century skills, prepare for STEM career paths and acquire STEM literacy, interest and engagement in STEM subjects.

The COVID-19 pandemic has undoubtedly had a significant impact on the education sector, leading to a shift from traditional classroom learning environments to remote and online learning modalities, which is also impacting students' learning experiences. When designing an effective distance and online learning environment, the learning environment itself should take centre stage (Singh & Thurman, 2019). Promoting change for constructive learning behaviour is also crucial, as students' online learning behaviour can be significantly and directly influenced by the dynamic interaction between their personal beliefs and the environment in which they find themselves (Abouzeid et al., 2021).

As described by Abouhashem et al. (2021), student engagement, interaction and persistence remain important aspects of STEM education delivered online. Therefore, research in STEM distance and online education is in high demand as it fosters numerous collaborative research initiatives around the world and continues to grow. For a more comprehensive understanding of the global research landscape in distance and online learning in STEM education, bibliometric analysis is an effective approach to visually assess

the vast scholarly data. Hong et al. (2019) suggest that bibliometric analysis can be performed using key information from a field of literature, collaboration networks, co-occurrence of keywords, burst words, etc.

Bibliometric methods using quantitative and statistical analysis tools have also long been used in library work and information retrieval (Zhang et al., 2022; Hassan et al., 2021). They work by analysing and filtering huge amounts of data to determine knowledge relationships between documents. It has been noted that the use of bibliometric analyses could enable subsequent researchers to build on the established foundations of specific domain studies (Ali & Tse, 2023). To provide interested researchers with a framework for their subsequent investigations in STEM education research, this methodology has been used in various research areas to facilitate comprehensive presentations (Cai et al., 2023; Merayo & Ayuso, 2022).

Methodology

To identify current trends in STEM education research related to distance and online learning, a bibliometric analysis method was used in this study. This method was chosen because bibliographic data can be used to create a record of work that includes a compilation of books, articles, documents, publications, and other materials typically related to a single topic or related topics. The data for this study was taken from the Scopus scholarly database, which can be accessed at <https://www.scopus.com>. It is one of the most comprehensive databases for citations, summaries and abstracts of literature, including scientific journals, books, proceedings and conferences, and is freely accessible via the Internet (AlShehhi et al., 2022). It is the most important database for abstracts and citations in research worldwide. This study consists of four steps, which are described in the following sections.

Research Design

The purpose of the bibliometric analysis in this study is to explain the research questions. To answer the first research question, the publications were analysed by year, focusing on citation analysis, document categories and publication source. The topic and keyword analyses matched the main areas described in the research question. The thesis also examined the main institutions, the countries with the most contributions and analysed authorship in response to the research questions.

Bibliometric Data

The study used the Scopus database to search for documents with the following query: "science AND technology AND engineering AND mathematics AND education AND distance education OR online learning" On 6 January 2024, the study received 648 documents, using a filter that only considered publications from 2023. The data was cleaned to remove duplicates and a collection of 648 documents covering the period from 1996 to 2023 was analysed. The data was exported to the corresponding documents in the form of bibliometric files in CSV Excel format.

Bibliometric Analysis and Visualization Maps

The study used VOSviewer software (version 1.6.20) to create and visualise bibliometric networks that include collaboration, co-citation and co-authorship links. This software uses distance estimates to approximate the similarity between objects such as organisations,

articles, journals and terms and to display these similarities visually (van Eck & Waltman, 2007). The programme can be downloaded from the website <https://www.vosviewer.com/>. It offers text mining functions for the creation and visualisation of co-occurrence networks using important phrases from scientific articles.

Three types of analyses were performed with VOSviewer: an initial study of co-authorship patterns based on nations, organisations and authors, a co-occurrence study of all keywords and a country-specific analysis of citation patterns. The keyword analysis was performed for primary institutions, countries with significant contributions, authorship analysis and citation analysis. In addition, network visualisations were used for the purpose of presentation. Then, the final phase involved explaining and analysing the results.

Results and Discussion

The insights gained from the bibliometric analysis relate to the following investigations: (1) the development and dissemination of research on distance and online learning in STEM education; (2) the exploration of the most important topics in the field of distance and online learning in STEM education; and (3) the identification of the most important people in research on distance and online learning in STEM education.

Development and Dissemination of Research on Distance and online Learning in STEM Education

In this study, the following data were analysed to answer the question about the development of distance and online learning in STEM education research and trends in dissemination: (1) number of publications by year; (2) sources for titles and document types; and (3) languages used in the documents. This section used analyses obtained directly from the Scopus database via the 'Analyse search results' function.

Number of Publications by Year

Studies on distance and online learning in STEM education began in 1996. Rensselaer Polytechnic Institute's undergraduate programme *was performed* a major reform that introduced studio courses as an alternative to extensive lectures. This integrated format and technology-integrated courses improved the learning environment for students and faculty. This study emphasises the importance of incorporating technology into STEM education (Wilson, 1996). The number of publications in the field of STEM education research has been increasing since 2019: over 50 publications have been documented since 2019 (Figure 1). In 2021, the highest number was 96, indicating an increasing focus on distance and online learning. In 2023, however, the number decreased due to various searches in the Scopus database.

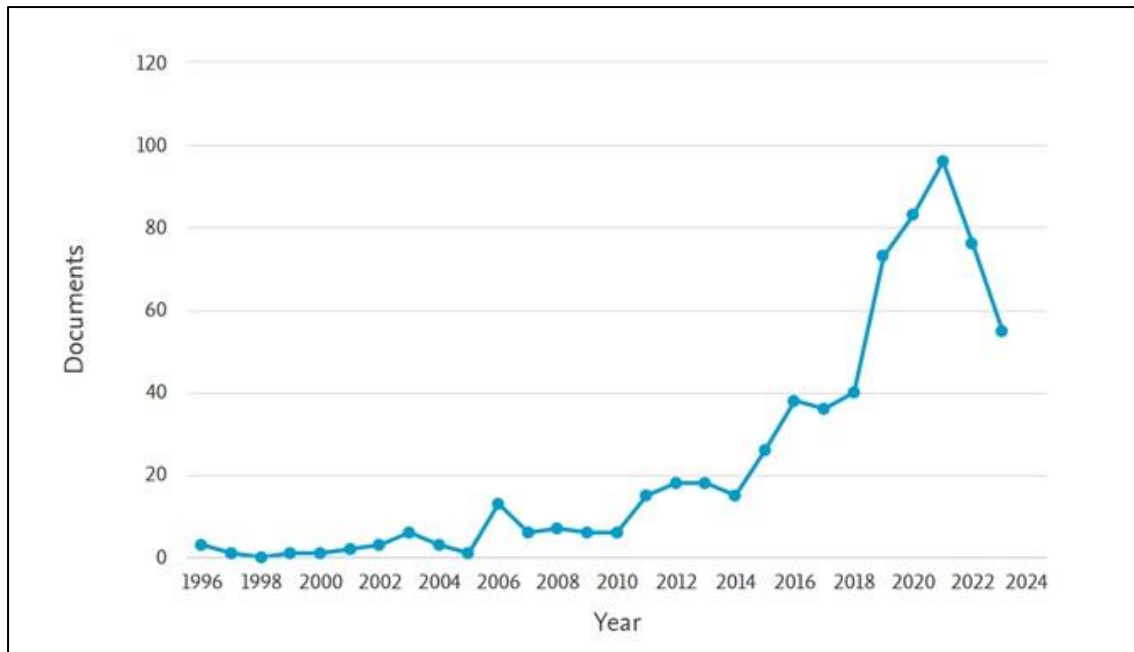


Figure 1. Annual Growth in STEM Education Research Publications (1996–2023)

Source of Titles and Document Types

The study analysed the sources for documents on distance and online learning in STEM education and showed that conference papers and articles were the most common sources (accounted for 92.3%), as shown in Table 1. Original research accounted for 88.4% of publications, with the most important documents published in academic journal. These results illustrate the importance of author contributions in the dissemination of research findings and provide insight into the number of publications and the amount of research in distance and online learning in STEM education. From the findings, 90 sources are contributed from the Conference Proceedings of the ASEE Annual Conference and Exposition, published since 1996. It is the most important source of publications on distance and online learning in STEM education. This publication accounts for 9.4% of all publications in this area, followed by the Proceedings of the of the Frontiers in Education Conference Proceedings Series, the Journal of Physics Conference Series, Advances in Intelligent Systems and Computing and Lecture Notes in Computer Science.

Table 1

Research sources for distance and online learning in STEM

Source type	Number of documents	Percentage (%)
Conference Paper	358	55.2
Article	215	33.2
Conference Review	25	3.9
Book Chapter	24	3.7
Review	14	2.2
Book	7	1.1
Note	3	0.5
Editorial	1	0.1
Retracted	1	0.1

Languages Used in Documents

Table 2 shows that English is the predominant language, accounting for 99.2 of the total amounts of publications on distance and online learning in STEM education. Other languages include Russian, Portuguese, Chinese, Bulgarian and Arabic. English is the preferred language for academic writing and international communication. According to Nazmiye Gürel Cennetkuşu (2017), English is considered the language of science for this reason. Consequently, several academic disciplines and research areas attach great importance to the choice of a publication language. Therefore, to facilitate access to their findings to the global academic community, it is crucial that researchers publish their work in the specialised language of their field (Liu & Buckingham, 2022). The results of this study show that the meaning, influence, and importance of the English language in academic communities and intellectual dialogue are crucial.

Table 2

Languages used for distance and online learning in STEM education publications.

Language	Number of documents	Percentage (%)
English	643	99.23
Russian	1	0.15
Portuguese	1	0.15
Chinese	1	0.15
Bulgarian	1	0.15
Arabic	1	0.15

Key Areas of STEM Education Research

The key areas of STEM education research were analysed in relation to (1) the topic area and (2) the keyword analysis.

Topic Area

Figure 2 shows that distance and online learning in STEM education has led to interdisciplinary research. Social sciences accounted for 26.3% of topics, followed by computer science and engineering with 20.4% and 24.3%, respectively. Multidisciplinary fields, including maths, accounted for 5.6% of the total. The natural sciences area covers a wide range of disciplines, including physics, astronomy, materials science, energy, biochemistry, genetics, molecular biology, chemical engineering, medicine, environmental science, agricultural and biological sciences, health professions, chemistry, immunology and microbiology, neuroscience and nursing. The social science area includes disciplines such as business, management, accounting, arts and humanities, economics, econometrics and finance. The study not only included scientific, technical, engineering and mathematical components, but also incorporated aspects from various social science disciplines.

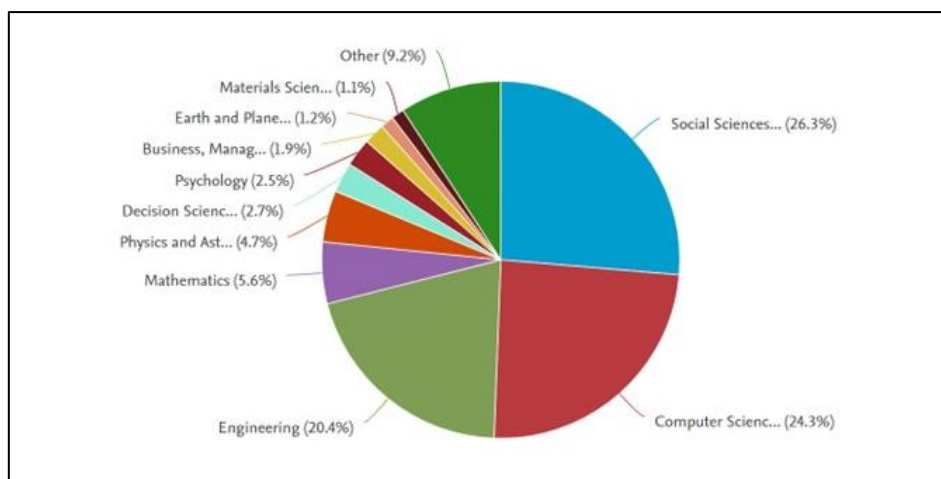


Figure 2. STEM education documents categorised by subject for distance and online learning.

Keyword Analysis

A bibliometric network map (Figure 3) graphically depicts the network of author keywords. Of the 1,532 terms analysed, 18 terms appear at least 10 times. In contrast to the remaining 75 keywords, STEM education had the highest frequency of occurrence ($n = 107$) and the strongest overall connections. Online learning, STEM education, COVID-19, education, distance learning, e-learning, higher education, and technology were other keywords with high link strength. As can be seen in the Figure 3, a similar font colour was also used to indicate the presence of common keywords, which served to differentiate them. The results of this study show that STEM education, technology, active learning, e-learning, distance learning, virtual reality and maths all have comparable levels of red. This indicates that these terms are closely related and occur frequently. This observation indicates that the words have comparable attributes, suggesting that they regularly occur together and are closely related.

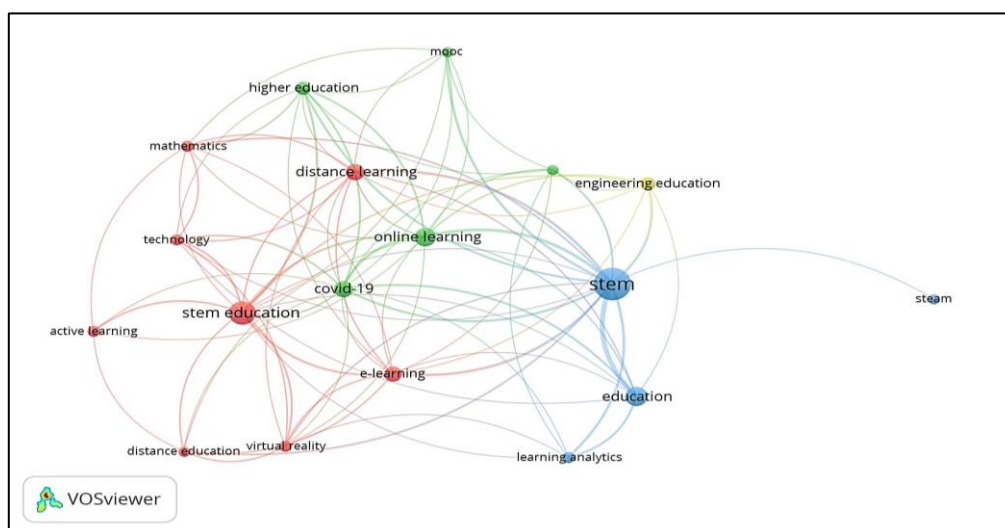


Figure 3. Author keywords with a minimum of ten occurrences represented as a network visualisation map.

According to Uddin & Khan (2016), keywords are crucial in a particular field of study. These findings are consistent with their conclusion. In addition, Comerio & Strozzi (2018) suggested

emphasising the importance of the keywords selected by the author in the keyword analyses. Besides, when analysed with VOSviewer, it was also found that 84 out of 3,758 with at least ten occurrences. The term "students" had the highest link strength with 281 other keywords. Other keywords included engineering education, e-learning, STEM education, curricula, educational informatics, distance learning and learning systems.

Key Players and Collaboration For Distance And Online Learning In Stem Education Research

In addition, the characteristics of scientific collaboration in STEM education research related to distance and online learning were also analysed, including: (1) the countries that contributed most frequently; (2) the primary institutions involved in STEM education research; (3) authorship analysis; and (4) citation analysis.

Countries with the Most Contributions to Research on Distance and Online Learning in STEM Education

There were 85 publications on distance and online learning in STEM education; the United States contributed the most with 39.4% of these publications. However, Germany, Canada, Spain, Australia, and Indonesia also made significant contributions to this topic. Table 3 lists the fifteen countries that have produced ten or more publications. The international distribution of the authors' national affiliations accounts for the remaining 37.7 % of the publications, which are spread across 70 countries. This result suggests that research has a significant impact on distance and online STEM education in different geographical areas.

Table 3

Geographic origins based on number of documents for distance and online learning in STEM education

Country	Number of documents	Publications (%)
United States	255	39.4
United Kingdom	37	5.7
Spain	35	5.4
Australia	32	4.9
Indonesia	32	4.9
Germany	30	4.6
China	23	3.5
Canada	20	3.1
Russian Federation	18	2.8
Greece	16	2.5
Malaysia	14	2.2
Taiwan	13	2.0
Portugal	12	1.9
Italy	10	1.5
Senegal	10	1.5

An assessment of the intensity of links between countries and publications based on the contributions of at least five documents using VOSviewer. The results show that thirty countries have met the minimum requirements. Figure 4 shows a network visualisation of the links between countries based on the co-authorship relationships. When influencing collaborative links with other countries, the United States had the highest aggregate link strength of 42. Germany, the United Kingdom, the Netherlands, Greece, Italy, Australia, Spain, Canada, and Switzerland had fewer links than the United States. The other countries had a

cumulative connection strength of less than 10. The data show that the degree of relatedness between countries is proportional to the distance between them. The strongest co-citation links were between the United States and Canada, as shown by the thickness of the lines.

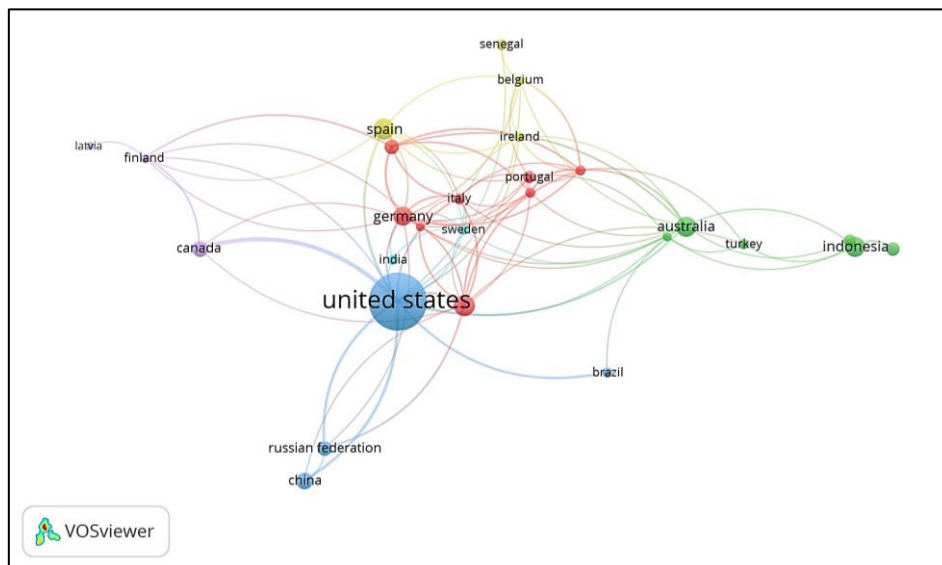


Figure 4. Graphical representation of the interconnectedness of nations based on their co-authorship relationships.

Analysis of Authorship

Data shows that 622 main authors are the major contributors to research on distance and online learning in STEM education. Two notable authors, Gillet from Ecole Polytechnique Fédérale de Lausanne and Ouya from Cheikh Anta Diop University, contributed significantly with seven publications each. The VOSviewer analysis was used to assess the links between authors and the citation frequency. The results show that the strongly linked authors were categorised into four categories based on co-authorship attribution, with Gillet playing a crucial role in linking the remaining fifteen authors. It was also demonstrated the US authors significantly improved their partnership links (Figure 5), with authors from several countries including China, Brazil, Russia, Senegal, Canada, Spain, Germany, Australia, the UK, Finland, Italy, Ireland, India, and Austria.

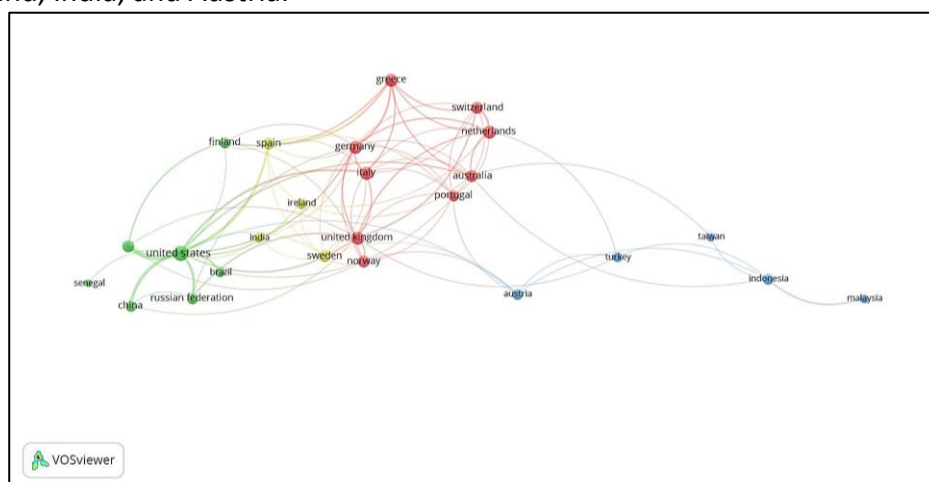


Figure 5. Network visualisation map that illustrates the links between co-authors based on their country of origin.

Citation Analysis

The citation analysis revealed that 47 out of 100 articles contained at least one document and ten citations per country. The United States had the most extensive network of linked citations, with 2,322 citations. Other countries such as the United Kingdom, Germany, Italy, Greece, the Netherlands, Spain, Australia, Canada, and Portugal followed suit. Researchers from the United States and Canada have close research relationships. In addition, the citation-based links between nations as displayed in Figure 5 above were grouped into eight categories. The cluster mapping displayed coloured citations and assigned countries to clusters based on their citation links as described in Table 4. This finding highlights the importance of authors recognising their fellow researchers as advisors, regardless of country of origin.

Table 4

List of nations based on relationships between online and distant learning in STEM education studies

Cluster 1	Cluster 2	Cluster 3	Cluster 4
Czech Republic	Austria	Estonia	Australia
France	Bangladesh	Germany	Indonesia
Norway	Cyprus	Greece	Malaysia
Portugal	Hungary	Italy	Oman
Romania	India	Kenya	Taiwan
Slovakia	Ireland	Netherlands	Turkey
Slovenia	Sweden	Switzerland	
Cluster 5	Cluster 6	Cluster 7	Cluster 8
China	Mexico	Brazil	Canada
Hong Kong	Nigeria	Israel	Finland
Kazakhstan	Spain	Sinegal	
Russian Federation	United Kingdom	United States	

Discussion

In this study, we performed a bibliometric analysis to gain a comprehensive understanding of publications on STEM education, particularly distance and online learning. The first study looked in depth at the development and distribution of research in this area. In 1996, the first publication addressed distance and online learning in STEM education. Since its introduction in 2008, this field has developed significantly and become widespread, eventually establishing itself as the dominant field by 2021. Many of the sources for documents in this area come from conferences, with conference proceedings being the predominant document type. This suggests that most researchers working on STEM education via distance and online learning preferred to present their findings at conferences. According to de Vries & Pieter (2007), these conferences are an optimal environment for fostering intra- and multidisciplinary dialogue. Considering the integration of science, technology, engineering, and mathematics (STEM) principles into STEM education, conferences are probably the optimal setting to facilitate interdisciplinary dialogues and promote intradisciplinary connections between researchers.

According to the results, most of the articles were written in English. However, the limited number of journals published in other languages should not be considered. This statement is

consistent with the concept that English is the primary form of communication within the scientific community and the most efficient approach to keeping scientists around the world informed of research discoveries. Considering variables such as journal, year of publication and length of paper, Di Bitetti & Ferreras (2016) found that English-language publications receive a greater number of citations than their non-English language counterparts. The wide accessibility of English-language publications to a wider range of people could contribute to the occurrence of this behaviour; however, further research is needed to identify additional aspects. However, it is vital that academic institutions recognise this difficulty and work to improve the teaching of English, particularly in the sciences.

Analyses of subject areas and keywords provide the most insightful perspective on the most important areas of distance and online learning in STEM education research. Unexpectedly, most research articles on distance and online learning in STEM education focused on the social sciences, while science, engineering and mathematics form the foundation of knowledge in STEM education. The integration of multiple disciplines has fostered innovation and the development of new concepts. As outlined by Gillet et al. (2019), the implementation of digital education for STEM facilitates the promotion of economic growth through the development of core competencies and transversal skills essential to STEM-related competencies. The use of inquiry-based learning and competency-based education thus enables individuals to acquire a variety of skills.

When considering education, learning and human factors, it is important not to neglect the fundamental issues of social science, despite the scientific foundation that forms the basis of STEM. This was confirmed by the results obtained when categorising all keywords according to their occurrence; students emerged as the most important keyword. Students are important keywords due to their central role in the educational process and subject matter. The frequency of keyword use could potentially influence the speed of investigation of potential research topics. Sjögarde & Didegah (2022) point out that the speed of development of topics could affect the number of future citations. Therefore, it is crucial that keywords have a positive influence on the rate of development of a particular topic area, as evidenced by their mention in previous scholarly publications in the field.

Collaboration between researchers and the number of published papers is increasing significantly in parallel with the flourishing of research in distance and online learning in STEM. In terms of STEM education research, the United States is a leader in distance and online learning. Since most of the prestigious institutions in this field are in and affiliated with the United States, it is reasonable to assume that the United States is a leader in STEM education research in distance and online learning. In terms of publications and research collaboration, the United States has shown the most extensive engagement with several nations around the world. This is evident in the many citations attributed to American authors, which also signifies a collaborative relationship with authors from other countries. Not surprisingly, the most influential and prolific authors in terms of number of scientific publications and citations are from the United States. Furthermore, the number of citations could have a significant impact on the visibility of distance and online learning in STEM education among scholars in different regions or countries.

Implications and Research Gap

The results of the analyses presented in this paper indicate that the findings of this study also have several limitations, which are described below.

Ambiguous Authorship Due to Various Factors

Publications that originate exclusively from the Scopus database and relate to the topics of "STEM education" and "distance and online learning" may lead to inconclusive results. In addition, the research focused exclusively on topics related to "distance and online learning" and "STEM education", as indicated by the title, abstract and keywords of the article. Consequently, the search excluded all additional materials on the topics of "distance and online learning" and "STEM education" that were not explicitly used in connection with these topics. It is also possible that authors may have provided multiple names or different variants when registering their works in Scopus, resulting in inaccurate information. Furthermore, we limited the analysis to prominent publications in the fields of "distance and online learning" and "STEM education" in the Scopus database. We did not include journals from other databases, such as WOS, in the analysis. Regarding the applicability of the findings of this study, it is advisable to consider the limitations.

Integration between Science and Non-Science Disciplines in STEM Education Research

Interestingly, the current trend in STEM education research topics was found to be most pronounced in the social science disciplines. This result shows that STEM disciplines are equally represented in non-science disciplines. Liu (2020) showed that a consideration between STEM and social sciences contributed to and reflected the alignment in teacher education. It can be concluded that adapting to and updating learning with the new developments in technology and engineering are crucial components in STEM education.

STEM in the Context of Teacher Education

Indeed, it is important to make the best use of technology to enhance learning and skills development. However, there is a concern that the representation of disciplines in STEM research and learning outcomes is not equitable, especially when social science research begins to dominate subject areas. Although STEM is about science disciplines, education itself is revolutionising the conventional approach to education, which no longer focuses solely on the formulaic approach, but on a more engaging and interactive learning environment. For teacher training, there is therefore a need for additional research to emphasise technological integration with the element of humanising educational values.

Conclusion

This study attempts to expand the existing knowledge on distance and online learning in STEM education by integrating meta-analyses and systematic literature reviews. It can be concluded that STEM education research has shown that distance and online education is widely used around the world. The interest in distance and online research in STEM education was particularly developed in the early 20th century. However, it was found that the critical topic areas were evenly disseminated in a multidisciplinary field despite focusing only on the STEM discipline. In addition, research collaboration also has implications for the broad issues of distance and online STEM research. English is the language in which communication takes place and enables important factors for research collaboration. In the future, researchers, practitioners, funding agencies and policy makers could conduct a more thorough study and

offer alternative viewpoints on current and future research orientations for digital and online learning in STEM education.

The examination makes contributions through both theoretical frameworks and relevant contexts within distance and online learning research for STEM education. The study utilises bibliometric methods to track scholarly development and collaboration patterns between different fields of STEM education and contributes theoretically to this bibliometric knowledge base. The investigation demonstrates distance and online teaching methods became essential components for STEM education after the COVID-19 pandemic began and throughout this period. This study examines worldwide research collaboration networks to find important contributors and explores main educational trends that drive global educational practise. The obtained contextual information proves helpful for policymakers alongside educators and institutions which aim to strengthen their digital education strategies. An evaluation of geographic and thematic patterns delivers evidence-based solutions to reach underprivileged areas and establish fair learning opportunities and reduce the differences between male and female students and rural and urban areas in STEM studies. Both academic institutions and education system administrators benefit from the knowledge developed through this research for their decision-making processes worldwide.

Recommendations for Future Research

This study provides important information on the use of online and distance learning in STEM education. It also highlights certain areas that require further investigation in the future. However, limitation is the data was retrieved based on Scopus database only. Future research could expand its scope by including these sources and provide a more complete picture of the field's development and dissemination patterns. The strong presence of the social sciences in STEM education research indicates a growing trend towards interdisciplinary studies. This raises important questions about how the integration of non-scientific disciplines influences teaching methods and learning outcomes, particularly in teacher education.

Future research should examine how the language barrier affects intercultural communication and the effectiveness of information exchange between languages. Ultimately, they would like to see better collaboration on long-term, comprehensive studies that examine how these tools impact students' schoolwork, particularly in STEM subjects such as science, technology, engineering, and maths. Such research could also explore the role of academic conferences in sharing and advancing knowledge in this area, especially as virtual and hybrid formats become more common. By addressing these gaps, future research can help to develop more effective and inclusive approaches to distance and online learning in STEM education.

Acknowledgements

The authors express gratitude to the Universiti Teknologi MARA, Cawangan Negeri Sembilan, Kampus Kuala Pilah, for providing the necessary facilities for this work. In addition, the authors would also like to thank the reviewers and the editor team for overseeing the publishing process of this research.

Disclosure Statements

The authors report there are no competing interests to declare.

References

- Abouhashem, A., Abdou, R. M., Bhadra, J., Santhosh, M., Ahmad, Z., & Al-Thani, N. J. (2021). A distinctive method of online interactive learning in STEM education. *Sustainability*, 13(24), 13909. <https://doi.org/10.3390/su132413909>
- Abouzeid, E., O'Rourke, R., El-Wazir, Y., Hassan, N., Ra'oof, R. A., & Roberts, T. (2021). Interactions between learner's beliefs, behaviour and environment in online learning: Path analysis. *The Asia Pacific Scholar*, 6(2), 38–47. <https://doi.org/10.29060/taps.2021-6-2/oa2338>
- Ali, M., & Tse, A. W. C. (2023). Research trends and issues of engineering design process for STEM education in K-12: A bibliometric analysis. *International Journal of Education in Mathematics, Science and Technology*, 11(3), 695–727. <https://doi.org/10.46328/ijemst.2794>
- AlShehhi, A. M. A., Nasir, B. B. M., Kilani, A., Abuhassna, H., & Awae, F. (2022). Exploring the role of diversity on management and attitude: A bibliometric analysis. *International Journal of Academic Research in Progressive Education and Development*, 11(3). <https://doi.org/10.6007/ijarped/v11-i3/15370>
- Cai, Z., Zhu, J., & Tian, S. (2023). Research progress of STEM education based on visual bibliometric analysis. *SAGE Open*, 13(3). <https://doi.org/10.1177/21582440231200157>
- Comerio, N., & Strozzi, F. (2018). Tourism and its economic impact: A literature review using bibliometric tools. *Tourism Economics*, 25(1), 109–131. <https://doi.org/10.1177/1354816618793762>
- De Vries, B., & Pieters, J. (2007). Knowledge sharing at conferences. *Educational Research and Evaluation*, 13(3), 237–247. <https://doi.org/10.1080/13803610701626168>
- Di Bitetti, M. S., & Ferreras, J. A. (2016). Publish (in English) or perish: The effect on citation rate of using languages other than English in scientific publications. *AMBIO*, 46(1), 121–127. <https://doi.org/10.1007/s13280-016-0820-7>
- Gillet, D., Tijani, B., Beheton, S., Farah, J. C., Dikke, D., Noutahi, A., Doran, R., Gomes, N. R. C., Rich, S., De Jong, T., & Gavaud, C. (2019). Promoting and implementing digital STEM education at secondary schools in Africa. <https://doi.org/10.1109/educon.2019.8725130>
- Hassan, W., Zafar, M., Duarte, A. E., Kamdem, J. P., & Da Rocha, J. B. T. (2021). Pharmacological research: A bibliometric analysis from 1989 to 2019. *Pharmacological Research*, 169, 105645. <https://doi.org/10.1016/j.phrs.2021.105645>
- Hong, R., Liu, H., Xiang, C., Song, Y., & Lv, C. (2019). Visualization and analysis of mapping knowledge domain of oxidation studies of sulfide ores. *Environmental Science and Pollution Research*, 27(6), 5809–5824. <https://doi.org/10.1007/s11356-019-07226-z>
- Liu, F. (2020). Addressing STEM in the context of teacher education. *Journal of Research in Innovative Teaching & Learning*, 13(1), 129–134. <https://doi.org/10.1108/jrit-02-2020-0007>
- Liu, Y., & Buckingham, L. (2022). Language choice and academic publishing: A social-ecological perspective on languages other than English. *Journal of Multilingual and Multicultural Development*, 1–15. <https://doi.org/10.1080/01434632.2022.2080834>
- Merayo, N., & Ayuso, A. (2022). Analysis of barriers, supports and gender gap in the choice of STEM studies in secondary education. *International Journal of Technology and Design Education*, 33(4), 1471–1498. <https://doi.org/10.1007/s10798-022-09776-9>

- Cennetkuşu, N. G. (2017). International students' challenges in academic writing: A case study from a prominent U.S. university. *Journal of Language and Linguistic Studies*, 13(2), 309–323.
- Pearson, G. (2017). National academies piece on integrated STEM. *The Journal of Educational Research*, 110(3), 224–226. <https://doi.org/10.1080/00220671.2017.1289781>
- Singh, V., & Thurman, A. (2019). How many ways can we define online learning? A systematic literature review of definitions of online learning (1988–2018). *American Journal of Distance Education*, 33(4), 289–306. <https://doi.org/10.1080/08923647.2019.1663082>
- Sjögårde, P., & Didegah, F. (2022). The association between topic growth and citation impact of research publications. *Scientometrics*, 127(4), 1903–1921. <https://doi.org/10.1007/s11192-022-04293-x>
- Uddin, S., & Khan, A. (2016). The impact of author-selected keywords on citation counts. *Journal of Informetrics*, 10(4), 1166–1177. <https://doi.org/10.1016/j.joi.2016.10.004>
- Van Eck, N. J., & Waltman, L. (2007). VOS: A new method for visualizing similarities between objects. In *Studies in classification, data analysis, and knowledge organization* (pp. 299–306). https://doi.org/10.1007/978-3-540-70981-7_34
- Wilson, J. M. (1996). Institution-wide reform of undergraduate education in science, mathematics, engineering and technology. In *Technology-based re-engineering engineering education: Proceedings of Frontiers in Education FIE '96, 26th Annual Conference* (Vol. 2, pp. 541–544). IEEE. <https://doi.org/10.1109/FIE.1996.572913>
- Zhang, L., Ling, J., & Lin, M. (2022). Artificial intelligence in renewable energy: A comprehensive bibliometric analysis. *Energy Reports*, 8, 14072–14088. <https://doi.org/10.1016/j.egyr.2022.10.347>