Journal of Turkish Science Education, 2025, *22*(4), 625-654.
DOI no: 10.36681/tused.2025.032

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

Research trends and emerging areas of interest from 2004 to 2024 in science education

Ulku Seher Budak[1], Sevda Yerdelen Damar[2]

[1]*Faculty of Education, Bogazici University, Türkiye, Corresponding author: ulku.budak@std.bogazici.edu.tr, ORCID ID: 0000-0002-4047-9920*
[2]*Faculty of Education, Bogazici University, Türkiye, ORCID ID: 0000-0002-5665-5140*

ABSTRACT
The purpose of this study was to examine the research papers published in 6 SSCI (Social Sciences Citation Index) Q1 (quartile 1) category journals in the field of science education between 2004-2024 years with regard to the most influential publications, prevailing themes, emerging areas of interest, existing and future relationships between topics, social interactions among authors and their affiliations. In this study, the bibliometric analysis was used for a more rigorous and evolution of the field of large amounts of scientific data. Performance analysis and science mapping analysis were performed using the VOSviewer programme. Publication-related metrics, citation-related metrics, and citation and publication-related metrics were documented for the performance analysis. For the science mapping analysis, citation analysis, co-authorship analysis, co-word analysis, and bibliographic coupling analysis were performed. While there was a sharp decline in the number of science education studies published in 2019, science education studies generally show an increasing trend. Science education studies originate mainly from the USA, Australia and England. Prevailing themes were identified: STEM education, chemistry education, scientific inquiry, teacher education, conceptual change, argumentation, and socio-scientific issues. It was found that the research interest of science researchers has changed from COVID-19 to the present (2019 to 2024). Systems thinking, equity, gender, science identity, engineering education, computational thinking, online education, and systematic reviews were identified as emerging areas of interest. This study provides important implications for multiple stakeholders, including science researchers, curriculum developers, science educators, and education policymakers.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
06.12.2024
Accepted:
27.01.2025
Available Online:
27.11.2025

KEYWORDS:
Science education, research trends, literature review, bibliometric analysis.

To cite this article: Budak, U.S., & Yerdelen Damar, S. (2025). Research trends and emerging areas of interest from 2004 to 2024 in science education. *Journal of Turkish Science Education, 22*(4), 625-654. http://doi.org/10.36681/tused.2025.032

Introduction

There is a strong consensus that pupils, who will be the citizens of the future, should be equipped with scientific literacy and scientific process skills, which are 21st-century skills (Turiman et al., 2012), and that these skills can be acquired in science classes (Trna & Trnova, 2015). Scientific literacy is a milestone for individuals to contribute to societal critical thinking on socio-scientific issues (Istyadji & Sauqina, 2023; Sengul, 2019). Therefore, scientific literacy provides a critical perspective for understanding science and society (Rudolph, 2024). When citizens are exposed to scientific ideas and their products daily, they will be better able to cope with these situations as they have scientific knowledge and practices of scientific thinking. Science education can also enable global citizens to participate actively and confidently in decision-making on complex socio-scientific and socio-technical issues (Fensham, 2002). Today, citizens face many complex challenges due to the interaction of human activities and global systems (Salvadó et al., 2013). Science education develops critical thinking skills that help learners tackle complex problems, and it has become even more important in the face of the interconnected challenges of the 21st century (Bayani et al., 2025; Demir, 2022; Maddens et al., 2020).

The increase in science education research has led to the need to analyse these studies and provide a roadmap for future research (Dogan, 2021). Trend analyses can illustrate trends in science education research, research gaps, and, thus, topics that need further research. Trend analyses can provide science educators, policymakers, and practitioners with a framework and insight into the state of science education research (Lee et al., 2009; Lin et al., 2014). While recognising the importance of science education research, it is also acknowledged that there are existing and emerging needs and challenges in science education research that need to be further explored (McFarlane, 2014). For example, there is a need to address climate change from a social and ecological perspective (Henderson et al., 2017), and teachers' science identities and the relationships between those and their scientific, personal, and collective identities (Zhai et al., 2024). Therefore, the motivation and effort of this study are to provide science education researchers with a good map of areas where more research is needed on such needs and challenges in science education.

Aim and Research Questions

This study aims to examine the studies published in SSCI Q1 category journals in the field of science education in the last two decades in terms of the most influential publications, current topics, existing and future relationships between topics, social interactions among authors and their affiliations, using bibliometric analysis. This study seeks to answer the following research questions.

RQ1: What are the trends in publications and citations in science education research?

RQ2: What are the leading authors by number of publications and citations in science education research?

RQ3: What are the most influential documents by number of citations in science education research?

RQ4: What are the prevailing themes and emerging areas of interest in science education research?

RQ5: What are the leading countries by number of publications and citations in science education research?

RQ6: What are the top institutions by number of publications and citations in science education research?

RQ7: What is the social interaction among authors and their affiliations in science education research?

Significance of the Study

Research in science education literature has been periodically analysed to identify prevailing themes. For example, prevailing themes in science education research have been analysed with trend analysis at five-year intervals from 1998 to 2017 (Lee et al., 2009; Lin et al., 2014; Lin et al., 2019; Tsai & Wen, 2005), and by bibliometric analysis from 1982 to 2021 (Tosun, 2022) and from 2001 to 2020 (Wang et al., 2023). However, as a result of the literature review conducted by the researchers of this study, it was found that the trending topics in science education in the post-COVID-19 period have not been investigated. The importance of this study is to show whether the research trends of science education researchers have changed, especially in the period after the pandemic that affected the world, and if so, which topics have increased interest. This bibliometric analysis is unique in that it covers the period when technology impacted the world during COVID-19 and its aftermath, providing researchers with current research gaps and showing the impact of the pandemic on research. This study shed light on prevailing themes and emerging areas of interest in high-impact science education journals and the impact of COVID-19 on research trends in science education. Since the journals indexed by the SSCI publish high-impact research from the international humanities and social sciences, it is important to examine the research trends in these journals (Chen & Du, 2016). The reason for focusing on SSCI Q1 journals in this study is to analyse high-impact research consistent with the goals of identifying influential publications and trends. SSCI Q1 journals are high-quality journals that publish only high-impact research, and articles published in these journals have higher average citations than other journals (Orbay et al., 2021). Therefore, this study aims to examine the studies published in SSCI Q1 category journals in the field of science education in the last two decades. The results of this study will provide policymakers, practitioners, and curriculum makers in the field of science education with information about the global trend in science education and will be useful as empirical research in their educational policymaking.

Literature Review

Systematic Reviews vs. Bibliometric Analyses

Depending on the purpose and research questions of the researchers, systematic review, meta-analysis, or bibliometric analysis can be used in literature review studies. Systematic literature reviews are preferred when the data set is manageable enough to allow for manual analysis when the scope of the review covers specific topics in science education, or for trend analysis over specific time periods (Abdullah, 2022; Donthu et al., 2021; Passas, 2024). While systematic literature reviews have the potential for researchers to make interpretation errors, bibliometric analyses, unlike systematic literature reviews, are based on quantitative techniques and, therefore, minimise researchers' interpretation errors (Donthu et al., 2021). Bibliometric analysis is a systematic method used to identify trends in a research topic, its impact on afield, and potential future directions of the study area by identifying gaps in the field (Abdullah et al., 2023; Passas, 2024). Bibliometric analyses examine huge amounts of scientific data more rigorously and evolutionarily than systematic literature reviews. It provides a good basis for looking holistically at the impact and trends in a particular field and identifying topics needing further research (MacCoun, 1998).

Research Trends Over Time

Research trends in science education have been addressed for specific periods in previous studies. For example, research trends in science education have been examined in five-year periods from 1998 to 2002 (Tsai & Wen, 2005), 2003 to 2007 (Lee et al., 2009), 2008 to 2012 (Lin et al., 2014), and 2013 to 2017 (Lin et al., 2019). Most of the published documents were empirical, with a total of 802 studies published in the *International Journal of Science Education, Science Education, and Journal of Research in Science Teaching* between 1998 and 2002. Conceptual change was reported to be the most studied topic, and there was also a significant increase in research studies on students' learning contexts and social, cultural, and gender issues. Similar to Tsai and Wen’s (2005) study, Lee et al. (2009) reported that the authors from Western counties made significant contributions to science education research in a total of 869 studies published in the same journals between 2003 and 2007 and that most of the published documents were empirical. However, the number of articles by authors from other countries was increasing. It is shown that the interests of science researchers shifted from concept learning and conceptual change to learning contexts, such as the learning environment, between 2003-2007 compared to 1998-2022. It was also found that the interest in learning conceptions, teaching, and goals, policy and curriculum increased between these years.

Lin et al. (2014) examined the trends in science education between 2008 and 2012. They found that 990 studies published in the same journals, in line with previous studies (e.g., Tsai & Wen, 2005) and most of the published documents were empirical. The research trends in these years were identified as learning contexts, science teaching, and conceptual learning. Articles on argumentation, inquiry-based learning, and scientific modelling were also found to be highly cited.

Lin et al. (2018) examined 1,088 studies published in the same journals between 2013 and 2017 for trends in science education research, which has been conducted every five years since 1998. While conceptual change was the prevailing theme from 1998 to 2002, the context of learning, science education, and conceptual learning were the prevailing theme from 2002 to 2017. Lin et al. (2018) noted that studies on inequality in science education, STEM education, and undergraduate research experiences may also be emerging areas of interest.

Tosun (2022) investigated the last 40 years of science education (1982–2021) research with the bibliometric analysis method and found that the number of studies has increased significantly since 2007 and there was a peak in the number of studies in 2020. It was reported that the most used keywords were STEM/STEAM education, nature of science, assessment, professional development, science, scientific literacy, argumentation, gender, and conceptual change. Tosun (2022) found that between 2007-2021, more studies on the nature of science and professional development in science education were revealed. It was also found that the interest in conceptual change, scientific literacy, chemistry education, and attitudes decreased between 2017-2021.

Wang et al. (2023) investigated the prevailing themes of science education research from 2001 to 2020 through bibliometric analysis and found that the interest in science education research has gradually increased. Consistent with previous studies, Tosun (2022) and Wang et al. (2023) found that the countries that produced the highest number of publications were dominated by authors from Western countries. Wang et al. (2023) found that the most influential publications in terms of the number of citations were on standards, methods, practice and reflection in science education. Wang et al. (2023) identified seven prevailing themes from 2001 to 2020: conceptual change, gender, scientific argumentation, professional development, science learning, evolution, and peer review. Although recent studies by Tosun (2022) and Wang et al. (2023) have identified current trends in science education, both studies methodologically selected SSCI journals from all quartiles. Differently, the current study contributes to the science literature by identifying influential publications and trends published only in high-impact SSCI Q1 journals (Orbay et al., 2021). While trends in science education research were examined by Tosun (2022) in the period 1982-2021 and Wang et al. (2023) in the period 2001-2020, it was found that trends in studies conducted post-COVID-19 were not addressed. Therefore, in this bibliometric study, trends post-COVID-19 were revealed by analysing studies conducted in science education in the last two decades (2004-2024) and the impact of COVID-19 on trends in science research was examined.

Methods

Data Collection

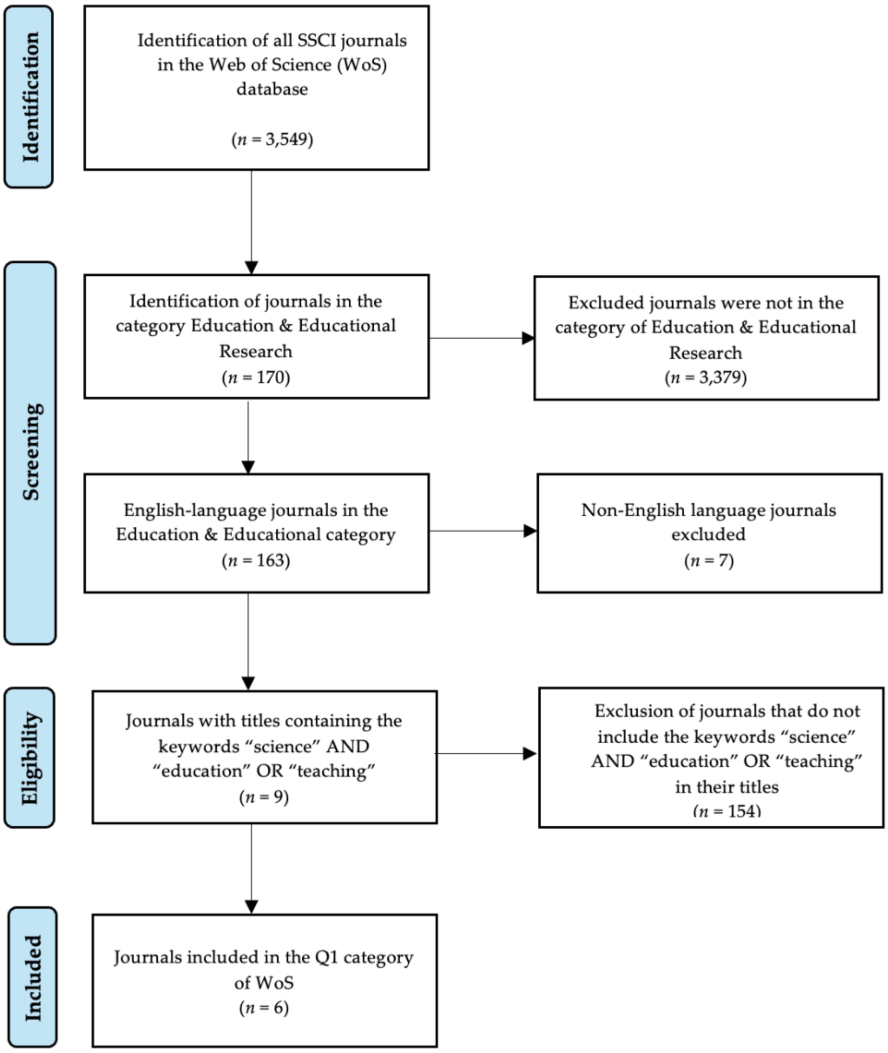
Journal Selection Process

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram was used to identify the journals included in this study. The PRISMA flow diagram is a systematic and rigorous framework for including and excluding studies in the literature according to specific criteria (Moher et al., 2009). In this study, the Web of Science Core Collection (WoS) was chosen as the database to reveal trends in science education because it provides “selective, balanced, and complete coverage of the world's leading research” (Birkle, 2020, p. 363). WoS provides researchers with raw data sets for bibliometric studies (Birkle, 2020). To identify journals from the WoS database, the researchers downloaded a list of all journals indexed in the Social Science Citation Index from the Web of Science Core Collection under the Education & Educational Research (E & ER) category.

The researchers filtered SSCI-indexed journals in English and the Education & Educational Research category in Excel, including “science” and “education” or “teaching” in the journal name. English-language journals were chosen because most international publications are written in English. The analysis of English-language journals is intended to make the bibliometric analysis of science education studies as comprehensive as possible. As a result of filtering the journals, nine journals were identified that met these criteria. From these journals, journals indexed in the SSCI Q1 category in the Web of Science Core Collection were purposively selected according to their Q-rank (quartile rank) categories. The Q1 category journals were selected as the dataset because they are the most prestigious and influential journals (Vijayan & Renjith, 2021). There were six science education journals with “science” and “education” or “teaching” in their titles, and the studies published in these journals constitute the data set of this study. The journals selected for this study are *Studies in Science Education*, *Journal of Research in Science Teaching*, *Journal of Science Education and Technology*, *International Journal of Science Education*, *Research in Science Education*, and *Science Education*.

Figure 1

Journal selection by using PRISMA flow diagram



Note. The figure was prepared according to the Moher et al. (2009) PRISMA flow diagram.

Article Selection Process

The Web of Science Core Collection database was accessed, and the journal name was entered in the "publication titles" section. Inclusion and exclusion criteria were set for selecting articles for this study. As an inclusion criterion, the publication date was set between 2004 and 2024, and articles outside these years were excluded. To examine emerging areas of interest in science education, this study limited the search to the last two decades, 2004-2024, which is the common preference for a great deal of review studies to determine the evolution in a field with a manageable and but also comprehensive examination of both fundamental and contemporary studies (e.g., Amiruddin et al., 2025; Li et al., 2025). Articles published in the selected journals were accessed on October 23, 2024, and articles added after this date were not included in the review. Articles, review articles, and early access studies were then filtered by document type in the WoS database to be included in the analysis.

The reason for including articles and review articles is that while articles present first-hand empirical findings, review articles systematically synthesize articles and provide a close lens on the issues studied in the field. Early access articles are included to provide a broader view of current trends in science education. Early access articles are articles that have been accepted for publication but have not yet been published in the journal. While including early access articles expands the dataset, it may also introduce inconsistencies as these articles may not have been finalized. Other document types such as editorials' letters, commentaries, proceedings, book chapters, book reviews, meta-analyses, working papers, and corrections, were excluded. After inclusion and exclusion criteria filtering, a total of 7,885 articles from *Studies in Science Education* (*n* = 118), *Journal of Research in Science Teaching* (*n* = 1,165), *Journal of Science Education and Technology* (*n* = 1,020), *International Journal of Science Education* (*n* = 2,397), *Research in Science Education* (*n* = 1,199), *Science Education* (*n* = 1,986) were included in this current study. The article selection process for each journal and the number of articles obtained as a result of this process are shown in detail in Table 1.

Table 1

Article selection process for each journal

Journal name	First search (Total number of articles between 2004-2024)	Second search (Journals limited to articles, review articles and early access)	Articles	Review articles
Studies in Science Education	167	118	75	43
Journal of Research in Science Teaching	1,257	1,165	1,139	26
Journal of Science Education and Technology	1,057	1,020	994	26
International Journal of Science Education	2,534	2,397	2,353	44
Research in Science Education	1,250	1,199	1,185	14
Science Education	2,666	1,986	1,940	46
Total	8,925	7,885	7,686	199

Data Analysis

The articles of each selected journal in the WoS database were saved as plain text files. The record content was the full record, and cited references in plain text files. The files of each journal were uploaded to the VOSviewer 1.6.19 (Van Eck & Waltman, 2023) for bibliometric analysis. Performance analysis accounts for the *contributions* of research constituents, whereas science mapping focuses on the *relationships* between research constituents" (Donthu et al., 2021, p. 287). The researchers determined thresholds (i.e., minimum citations) by testing various minimum citation numbers in the program to obtain the best representation of clusters in Vosviewer, which does not demonstrate small and uninteresting clusters (Van Eck & Waltman, 2023). Performance analysis and science mapping analysis metrics were performed with the following metrics (Donthu et al., 2021).

Performance Analysis

Publication-Related Metrics: The total number of publications, number of authors, and co-authored publications were analysed. To determine the number of publications by year for the science education journals selected for this study, the "analyse result" section of the Web of Science (WoS) database was filtered as "publication years" for each journal. The data were transferred into an Excel file. This Excel file was used by the researchers to compile and visualize the number of studies published annually in all journals over the last twenty years

Citation-Related Metrics: The total citations of research and average citations of research were analysed. To determine the number of citations of the science education journals selected for this study by year, the "citation report" was downloaded from the WoS database, and the results were transferred to an Excel file. This Excel file was used by the researchers to collect and visualise the total number of citations and the average number of citations of studies over the last twenty years in all journals by year.

Citation and Publication-Related Metrics: The number of cited articles by the year and the percentage of cited publications were analysed. To reveal the influential research in science education studies, the analysis type was selected as "citation" and the analysis unit was selected as "documents" in the VOSviewer program.

Science Mapping

Citation Analysis*:* Authors, organisations and countries were analysed. The 7,885 articles in the WoS database were published by authors from 3,011 institutions in 107 countries. To identify the leading countries in terms of the number of science education studies and the number of citations, the type of analysis in the VOSviewer program was selected as "citation", and the unit of analysis was selected as "countries". To identify the leading institutions in terms of the number of science education studies and the number of citations, the type of analysis in the VOSviewer program was selected as "citation" and the unit of analysis was selected as "organizations".

Co-Authorship Analysis: Leading authors and distribution of publications by country and institution were analysed. In analysing the collaboration of countries producing science education research, the type of analysis in the VOSviewer program was selected as "co-authorship", and the unit of analysis was selected as "countries". The collaboration of institutes producing studies in science education was analysed by selecting the analysis type as "co-authorship" and "organisations" as the analysis unit in the VOSviewer program. There are 3,011 institutions in the database that have produced publications in science education. To map the co-authorship networks in science education studies, the VOSviewer program selected "co-authorship" as the analysis type and "authors" as the analysis unit. There are 13,073 authors in the database and 675 authors with five or more publications.

Co-Word Analysis: Prevailing themes are defined as current or periodic topics while emerging areas of interest are topics that have been studied recently and may become trending topics in the future. The change in prevailing themes over the years is important in showing how research interests and intensities in science education have evolved (Lin et al., 2014). The frequency of the author's keywords in the articles was used as a criterion to identify prevailing themes and emerging areas of interest. Co-word analysis is a complementary analysis method used to provide supportive and complementary insights on the trending themes derived from bibliographic coupling (Chang et al., 2015). For the co-word analysis, “co-occurrence” is the analysis type and “author keywords” is the analysis unit in the VOSviewer program. For the analysis, only keywords with a minimum frequency of 30 or more were selected to focus on the most representative terms in the field. Thus, 76 out of 10,056 author keywords met this threshold. Prevailing themes provide an insight into major research themes and emerging areas of interest in science education.

Bibliographic Coupling Analysis: A bibliographic coupling analysis was conducted to analyse the prominent topics in science education research over the last two decades. This method is used to understand the current evolution of science education (Donthu et al., 2021). Bibliographic coupling analysis is based on the principle that a reference shared by two studies is a subject link between those studies (Kessler, 1962). For the bibliographic coupling analysis, “bibliographic coupling” was selected as the analysis type and “document” as the analysis unit in the VOSviewer program. For the analysis, only documents with 30 or more citations were included to focus on studies that best represent the field. Thus, 2,052 out of 7,885 science education studies met this threshold.

Reliability and Validity of the Study

Several steps were taken in the present study to ensure the reliability and validity of the analysis. First, the type of analysis- bibliometric analysis- is considered a reliable method employing a transparent, objective, and reproducible review process (Bretas & Alon, 2021; Donthu et al.,2021; Van Raan, 2014). Second, the bibliometric data was obtained from the Web of Science, a reliable database covering high-impact peer-reviewed journals (Zhang et al., 2023). Third, a representative sample of articles in science education was selected by including all articles that met the selection criteria based on PRISMA flow diagram. Fourth, thesaurus files for all science mapping analyses were created to handle erroneous entries and duplicates in the bibliometric data, which negatively influences the validity and reliability of the interpretation of the results (Donthu et al., 2021; Van Eck & Waltman, 2023). Data cleaning while creating the science map is necessary to accurately represent the data because author names, organisation names, country names, and document names may appear in different versions of different documents (Van Eck & Waltman, 2023). For example, “krajcik, j”, “krajcik, joe”, “krajcik, joseph”, and “krajcik, js” are different name combinations of the same author in the database. Fifth, the first author conducted the analyses; the second author checked all analysis results, and any disagreements between the two researchers were resolved until an exact agreement was reached.

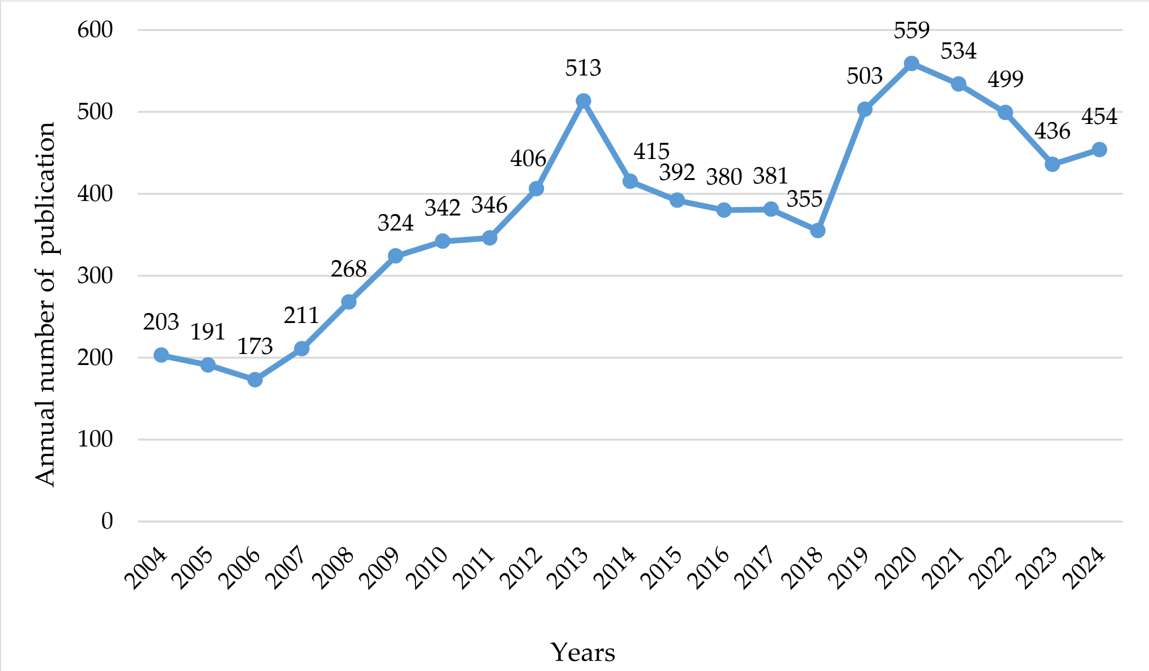
Findings

Publication and Citation Trends

Figure 2 shows the annual number of publications in science education research. In 2004, 203 studies were published, which decreased to 173 in 2006. After 2006, there was an acceleration in the number of publications, while there was a slow increase between 2009 and 2011. In 2013, there was a peak with a total of 513 publications, while there was a sharp decline in the number of publications between 2013 and 2018. In 2020, the second peak in the number of publications was reached, while a sharp decline was observed in 2023. In 2024, the number of science education articles increases again (Figure 2).

Figure 2

The annual number of publications in science education research

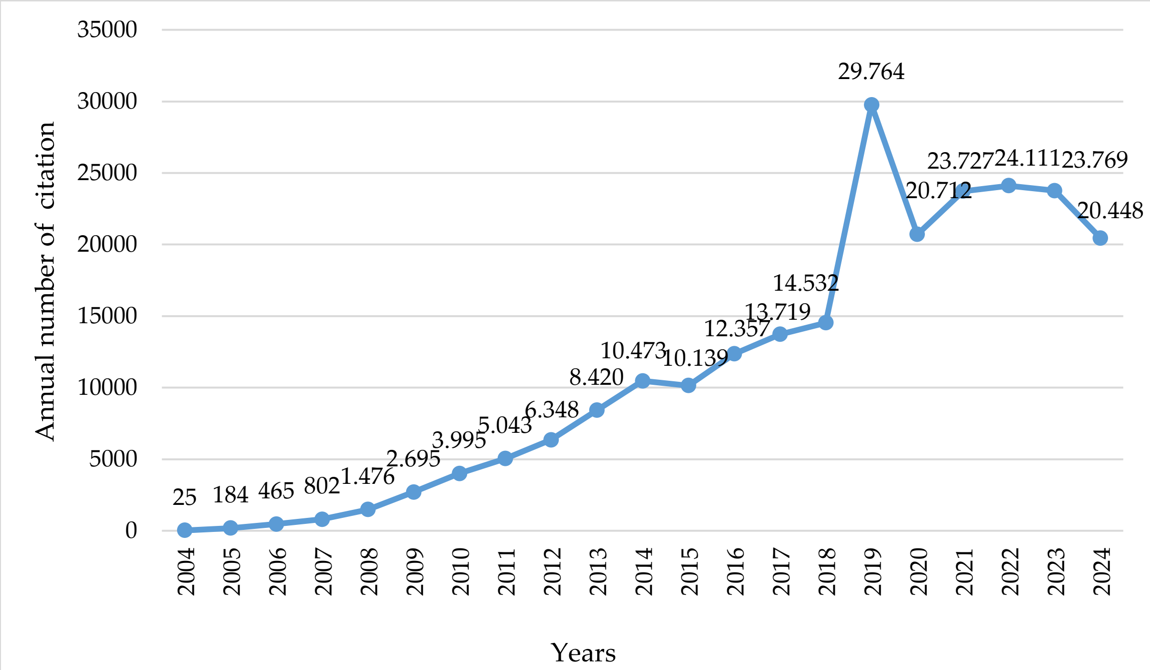


Publication and Citation Trends

Figure 3 presents the annual number of citations in science education research. In 2004, the studies received a total of 25 citations, and the citations received by the studies increased steadily until 2014, with a slight decrease in the number of citations in 2015. Between 2015 and 2018, the number of citations accelerated and reached its first peak in 2019 with 29,764 citations. In 2020, there was a sharp decline in the number of citations, but a slight increase was observed in the following years. In October 2024, the number of citations of science education research is currently 20,444. In summary, Figure 3 shows that there is a growth peak in the number of publications and an upward trend in the number of citations of science education research, except for very short periods.

Figure 3

The annual trend of citations in science education research



Prolific Authors

Influential authors are the backbones that lead academia in terms of their research topics, and the number of publications and citations of the author is an important criterion in evaluating prolific authors (Wang et al., 2023). As shown in Table 2, Tsai Chin-Chung is the most prolific and prominent author in science education in terms of total number of publications. The number of articles published by the top 10 authors accounts for 5.27% (n = 416) of the total articles (n = 7.885).

Table 2

Top 10 most prolific authors

Prolific authors	Total number of publications	Total number of citations
Tsai, Chin-Chung	72	3,381
Krajcik, Joseph S.	48	3,680
Sadler, Troy D.	46	4,959
Mcneill, Katherine L.	38	2,404
Erduran, Sibel	37	2,446
Roth, Wolff-Michael	37	1,319
Treagust, David F.	36	902
Hand, Brian	35	1,059
Jones, Melissa G.	35	748
Abd-el-khalick, Fouad	32	2,011
Total	416	22,909

Most Influential Documents by Total Number of Citations

In this study, there are 384 studies with 100 or more citations out of 7,885 science education studies included in the review. Of these studies, 3.65% belong to *Studies in Science Education* (*n* = 14), 28.64% to *Science Education* (*n* = 110), 4.69% to *Research in Science Education* (*n* = 18), 7.03% to *Journal of Science Education Technology* (*n* = 27), 35.94% to *Journal of Research in Science Teaching* (*n* = 138), 20.05% to *International Journal of Science Education* (*n* = 77).

Figure 4 shows the research networks of science education studies with 100 or more citations. The size of each node represents the number of citations that study has received. The lines between nodes indicate co-citation relationships between studies. Taber (2018), Hofstein and Lunetta (2004), Carlone and Johnson (2007), Seymour (2004), Osborne et al. (2004), Hunter et al. (2007), Minner et al. (2010), Dunleavy et al. (2009), Schwarz et al. (2009), Weintrop et al. (2016) have the most cited studies.

Figure 4

The research networks of science education studies with 100 or more citations

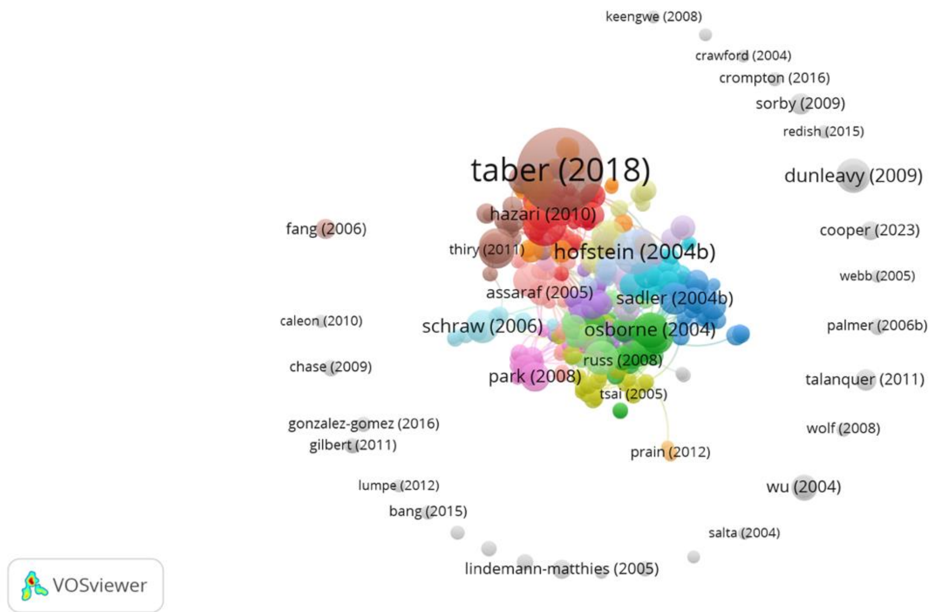


Table 3 shows the 10 most influential documents according to the total number of citations. These studies can be categorised according to their topics as follows: research methodology (Taber, 2018), laboratory in science education (Hofstein & Lunetta, 2004), science identity (Carlone & Johnson, 2007), argumentation in science education (Osborne et al, 2004), undergraduate research experiences (Hunter et al., 2007; Seymour, 2004), inquiry-based science education (Minner et al., 2010), augmented reality (Dunleavy et al., 2009), science modelling (Schwarz et al., 2009), computational thinking (Weintrop et al., 2016).

Table 3

Top 10 most influential documents by total number of citations

Article title	Reference	Journal title	Number of citations	Average citations per year
The use of Cronbach's Alpha when developing and reporting research instruments in science education	Taber, 2018	Research in Science Education	4,345	724.17
The laboratory in science education: Foundations for the twenty-first century	Hofstein & Lunetta, 2004	Science Education	1,194	59.70
Understanding the science experiences of successful women of color: Science identity as an analytic lens	Carlone & Johnson, 2007	Journal of Research in Science Teaching	1,135	66.76
Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study	Seymour, 2004	Science Education	773	38.65
Enhancing the quality of argumentation in school science	Osborne et al., 2004	Journal of Research in Science Teaching	739	36.95
Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development	Hunter et al., 2007	Science Education	739	43.47
Inquiry-based science instruction-What is it and does it matter? Results from a research synthesis years 1984 to 2002	Minner et al., 2010	Journal of Research in Science Teaching	731	52.21
Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning	Dunleavy et al., 2009	Journal of Science Education and Technology	710	47.33
Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners	Schwarz et al., 2009	Journal of Research in Science Teaching	690	46.00
Defining computational thinking for mathematics and science classrooms	Weintrop et al., 2016	Journal of Science Education and Technology	668	83.50

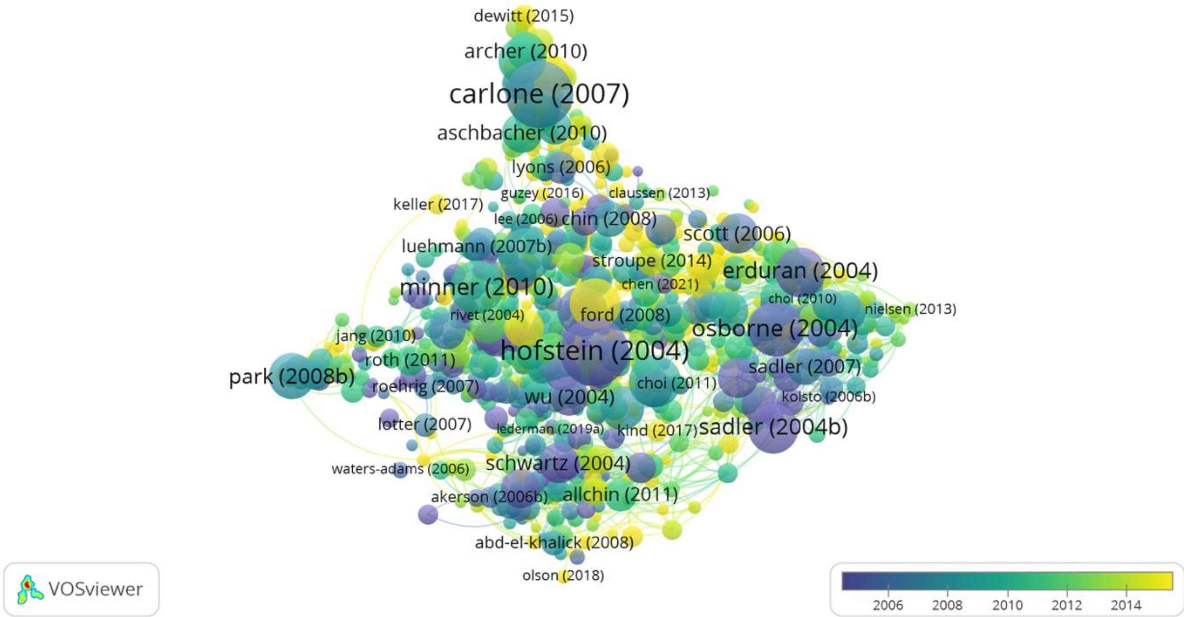
Prevailing Themes and Emerging Areas of Interest in Science Education in the Last Two Decades

Figure 5 shows the bibliographic coupling analysis of documents for present or periodical themes in science education research. An examination of trends in science education research by year revealed that the themes such as laboratory in science education (e.g., Hofstein & Lunetta, 2004), socio-scientific issues in science education (e.g., Sadler, 2004), inquiry in science education (e.g., Abd-El-Khalick et al., 2004), nature of science in science education (e.g., Schwartz et al., 2004), argumentation in science education (e.g., Erduran et al., 2004) were predominantly studied in 2004.

It has been shown that over time, topics such as argumentation (e.g., Berland & Reiser, 2009; Berland & McNeill, 2010), inquiry (e.g., Minner et al., 2010; Ruiz-Primo & Furtak, 2007; Schwarz et al., 2009), and socio-scientific issues (e.g., Zeidler et al., 2009) have continued to be studied, and in addition, new topics such as self-efficacy (e.g., Britner & Pajares, 2006), pedagogical content knowledge (e.g., Park & Oliver, 2008), and augmented reality (e.g., Dunleavy et al., 2009) have begun to be explored. Trends in recent last ten years have shifted toward career aspiration (e.g., DeWitt & Archer, 2015), secondary school students, computational thinking (e.g., Weintrop et al., 2016), new teaching methods (e.g., González-Gómez et al., 2016), STEM education (e.g., Guzey et al., 2016), artificial intelligence (e.g., Cooper, 2023), gender, ethnicity, diversity, equity, minority, and marginalised groups (e.g., Archer et al., 2015; Carpi et al., 2017; Dou et al., 2019; Ong et al., 2018) (see Figure 5).

Figure 5

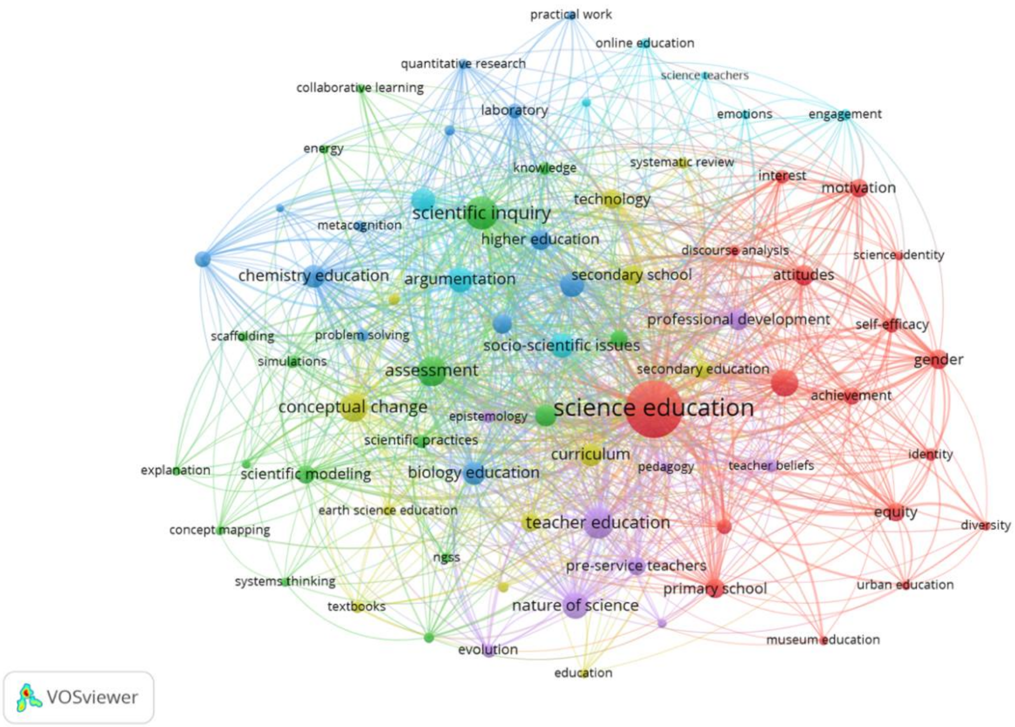
Bibliographic coupling analysis of documents for prevailing themes and emerging areas of interest in science education research



Themes derived from bibliographic coupling analysis may tend to be general, as they are derived from the citation relationships in the references of the studies. As shown in Figure 6, the topics in science education are clustered into six groups. These clusters are shown in blue, green, purple, yellow, turquoise and red colours. The dominant keywords in each cluster are determined by the number of links. Figure 6 shows that the main keyword is "science education". The dominant keywords in the blue cluster are "chemistry education", in the green cluster "scientific inquiry", in the purple cluster "teacher education", in the yellow cluster "conceptual change", in the turquoise cluster "argumentation and socio-scientific issues" and in the red cluster "STEM education". The dominant words in the turquoise cluster are "argumentation and socio-scientific issues" as both argumentation and socio-scientific issues have the same number of links with 59 links.

Figure 6

Relationships among topics in science education research



Note. Although all keywords are included in the analysis, some of them may not be clearly visible in the figure due to overlaps in the science mapping.

Table 4 shows all keywords in each cluster in detail. To be objective, cluster labels were chosen from the highest number of linking words in each cluster.

Table 4

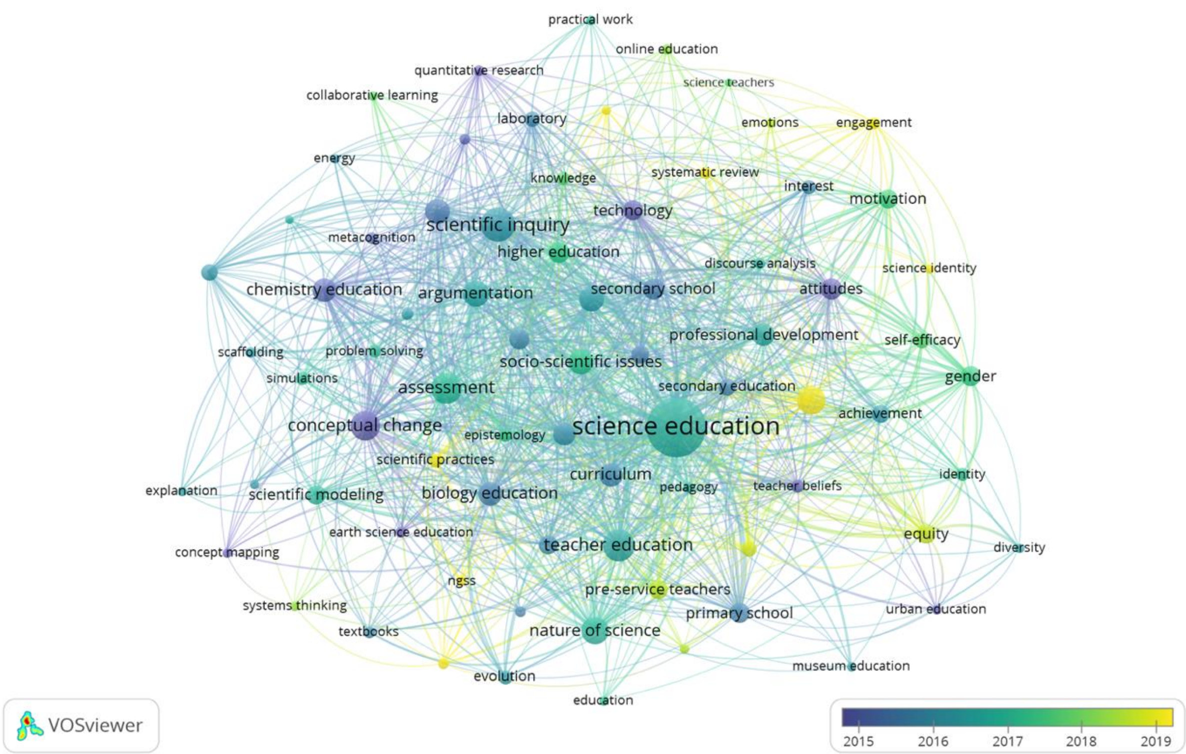
Trending topic clusters and author keywords in science education research

Cluster labels	Author keywords
STEM education	Achievement, attitudes, discourse analysis, diversity, engineering education, equity, gender, identity, interest, motivation, museum education, primary school, science education, science identity, self-efficacy, stem education, urban education
Scientific inquiry	Assessment, collaborative learning, computational thinking, concept mapping, energy, explanation, knowledge, learning, middle school, Next Generation Science Standards (NGSS), representations, scaffolding, scientific inquiry, scientific modelling, scientific practices, simulations, systems thinking
Chemistry education	Biology education, chemistry education, context-based learning, higher education, laboratory, learning environment, metacognition, physics education, practical work, problem solving, qualitative research, quantitate research, scientific reasoning
Conceptual change	Astronomy education, conceptual change, curriculum, earth science education, education, environmental education, secondary education, secondary school, systematic review, technology, textbooks, visualization
Teacher education	Early childhood, epistemology, evolution, nature of science, pedagogy, pre-service teachers, professional development, teacher beliefs, teacher educations
Argumentation and socio-scientific issues	Argumentation, critical thinking, emotions, engagement, online education, science teachers, scientific literacy, socio-scientific issues

Figure 7 shows the evolution of prevailing themes in science education research over the years. It was found that the “conceptual change”, “scientific inquiry”, “professional development”, “argumentation”, “nature of science”, “assessment”, and “metacognition” topics were predominantly studied until 2019. From the years of COVID-19 to the present (2019 to 2024), there is an increasing trend for topics in STEM education (e.g., Anwar et al., 2022), systems thinking (e.g., Budak & Ceyhan, 2024), equity (e.g., Hinojosa et al., 2021), gender (e.g., Chen et al., 2024), science identity (e.g., Chen & Wei, 2022), engineering education (e.g., Chabalengula & Mumba, 2017), computational thinking (e.g., Christensen & Lombardi, 2023), online education (e.g., Saribas, 2023), and systematic reviews (e.g., Ormanci et al., 2015) to be emerging areas of interest.

Figure 7

Emerging areas of interest by years



Note. Although all keywords are included in the analysis, some of them may not be clearly visible in the figure due to overlaps in the science mapping.

Leading Countries

Out of 107 countries, the number of countries publishing more than 20 articles is 39 (36.5%). Table 5 shows the leading countries by total number of publications. Authors in the United States of America (USA), Australia, and England are the top three in terms of the number of articles published, with more than 500 articles. In first place, with a very large gap difference, authors in the USA published 3,445 articles, accounting for 43.69% of the 7,885 articles included in this study. The contribution of the top 10 countries to science education studies is 87.66% (n = 6,912) of all published articles selected in this study (n = 7,885). Authors from the USA, Australia and England are in the top three in terms of number of citations, having published papers with more than 14,000 citations.

Table 5

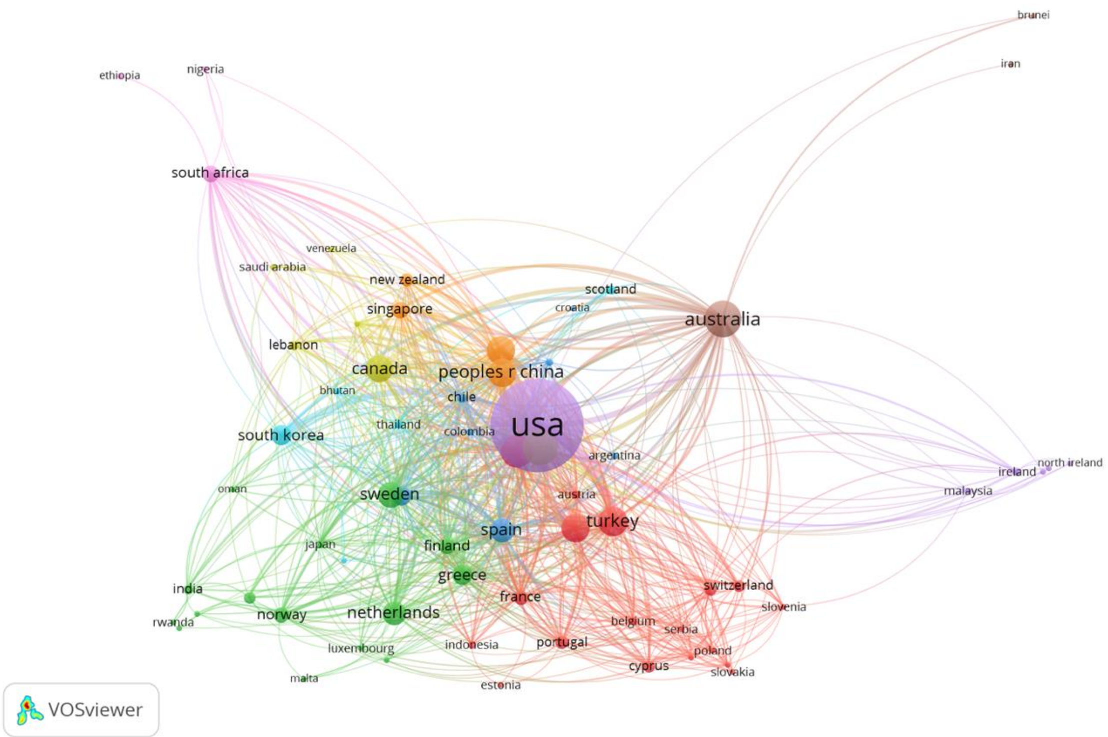
Leading countries by total number of publications

Leading countries	Total number of publications	Total number of citations
USA	3,445	126,107
Australia	561	14,853
England	526	23,685
Germany	410	8,858
Turkey	367	7,571
Peoples R China	344	3,728
Taiwan	340	9,831
Israel	337	11,777
Canada	308	8,345
Sweden	274	4,764
Total	6,912	219,519

Figure 8 shows the scientific network between countries collaborating on five or more publications out of 107 countries (n = 67). In Figure 8, node size positively correlates with the number of co-authored papers, and the link arrows indicate collaborations between countries. The USA has the highest number of partnerships with 59 countries in science education research and collaborates most often with Australia, Turkey, and Ireland. After the USA, England, Australia, Germany, Turkey and the People's Republic of China were the countries that collaborated most with other countries (see Figure 8).

Figure 8

Collaborative research networks between countries that collaborate on 5 or more publications



Leading Institutions

Table 6 shows the top ten institutions by total number of publications. Authors from Michigan State University (USA), National Taiwan Normal University (Taiwan), and Weizmann Institute of Science (Israel) published more than 100 articles, making them the top three most productive institutions. These three institutions accounted for 5.31% of the total number of articles published (n = 419), while the contribution of the top 10 institutes in Table 6 to science education studies was 13.58% of the total number of articles published by all the institutions (n =1,071) selected in this study.

Table 6

Leading institutions by total number of publications

Leading institutions	Total number of publications	Total number of citations
Michigan State Univ	158	6,867
Natl Taiwan Normal Univ	150	3,778
Weizmann Inst Sci	111	6,234
Purdue Univ	97	2,496
Univ Missouri	96	3,151
Univ Illinois	94	4,257
Nanyang Technol Univ	93	3,292
Univ Michigan	93	6,015
Univ Georgia	92	3,693
Indiana Univ	87	6,534
Total	1,071	46,317

Leading Institutions Social Interaction among Authors and their Affiliations in Science Education Research

Figure 9 shows the collaborative research networks of authors with five or more publications. The size of the nodes in Figure 9 is directly proportional to the number of citations received by the authors. If there are co-authorship relationships, these are also indicated by links. Among the top 10 authors by number of publications, Tsai Chin-Chung, Krajcik Joseph S., Jones Melissa Gail, Sadler Troy D., Mcneill, Katherine L., and Treagust David F. are the most collaborative authors. It was found that Tsai Chin-Chung established a collaboration with Chang, Hsin-Yi, Wu, Hsin-Kai, and Chen, Sufen and worked on technology in education, science education trends, and TPACK (Technological Pedagogical and Content Knowledge) and the nature of science. Krajcik, Joseph S. worked with Mcneill, Katherine L. on learning with science inquiry, Wu, Hsin-Kai on project-based science, and Delgado, S. on pedagogical curriculum. Treagust, David F. worked with Tang, Kok-Sing, and Won, Mihye on conceptual understanding and chemical representations. In general, while there is also collaboration among small groups, the strength of their linkages is weak, and collaborations appear to occur predominantly between specific groups.

Figure 9

Social interaction among authors with five or more publications

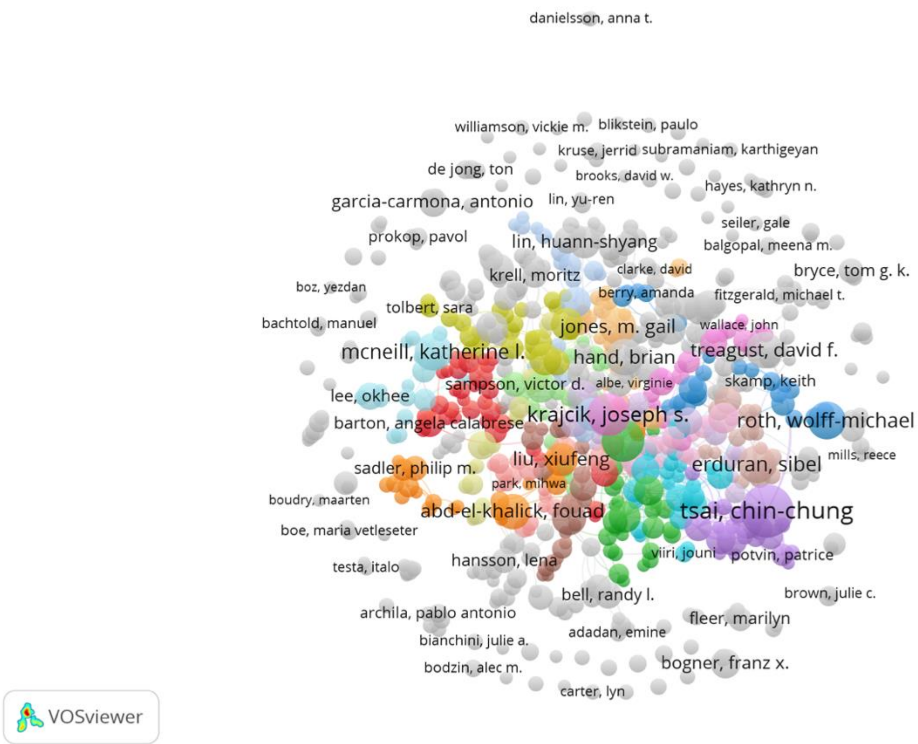
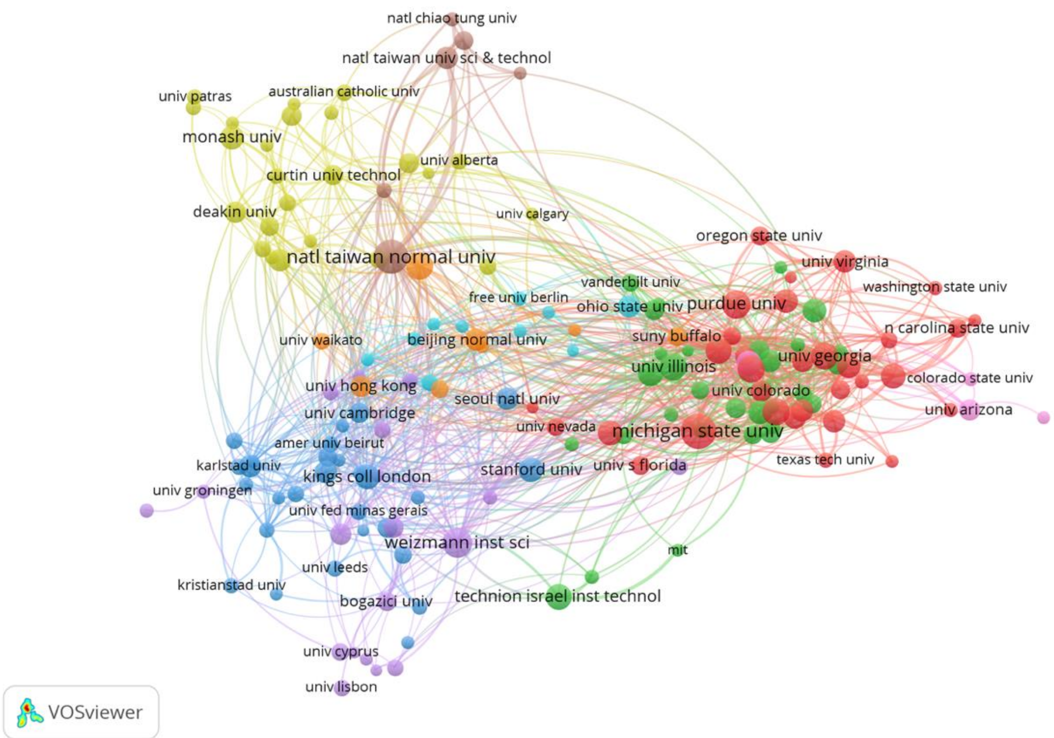


Figure 10 shows the collaborative research networks among these institutions that collaborated on 20 or more publications (n = 162). As shown in Figure 10, Michigan State University (USA), the institution with the most publications, leads as the most collaborating institution with 61 connections. It is followed by Indiana University (USA) with 57 links and National Taiwan Normal University (Taiwan) and Weizmann Institute of Science (Israel) with 51 links each. In summary, while large research institutions tend to collaborate with North America, research institutions in Europe also collaborate with less connected research institutions than in North America.

Figure 10

Social interaction among authors affiliations that have collaborated on 20 or more publications



Discussion

This study provides an overview of prevailing themes and emerging areas of interest in science education research published in the WoS database in six SSCI Q1 index journals over the past two decades (2000 to 2024). This study revealed that although there are fluctuations in the number of science education studies from time to time, there is a general trend of increasing number of publications. These findings are consistent with previous trend studies in science education from 1998 to 2002 (Tsai & Wen, 2005), 2003 to 2007 (Lee et al., 2009), 2008 to 2012 (Lin et al., 2014), and 2013 to 2017 (Lin et al., 2019). This study revealed that the number of citations was low in 2004 year in the WoS database for selected journals. This may be due to the low citation rates in the humanities, which may be due to the low number of linked references citing articles published in the core journals indexed in the WoS database (Marx & Bornmann, 2015). It was also found that the total number of citations of the studies published in all journals in the last twenty years was 233,204, and there were 29.57 citations per article. The results of this study are consistent with the findings of Wang et al. (2023) in the sense that while there was a very slow growth in the number of citations in the first four-year period (2004 to 2008), there was a dynamic growth in the number of citations. However, there were fluctuations in the number of studies published from 2008 to the present. This is one of the important findings in terms of highlighting the increasing interest in science education in recent years (Wang et al., 2023). The underlying factors driving science education research trends may be related to major events, societal, technological, or policy changes, funding changes, or influential special issues in journals. The decline in citations after 2020 could be a global disruption of the COVID-19 pandemic, as published research by science researchers has declined sharply after this period.

Prolific authors are motivated by an unwavering passion to continue their work (Mayrath, 2008) and see it as a "labour of love" (Kiewra & Creswell, 2000, p. 156). Tsai, Chin-Chung, was the most prominent prolific author compared to other researchers, with over seventy articles in 6 science education journals examined. These findings are consistent with the findings of Wang et al. (2023) but inconsistent with the findings of Tosun (2022), as Tosun (2022) found that the most prolific author was Roth, Wolff-Michael. In the present study, Roth, Wolff-Michael ranks sixth in the place of most productive authors. Thus, Tsai, Chin-Chung played an important role in disseminating knowledge to science education research. In terms of the number of citations, Sadler, Troy D., Taber, Keith S., and Osborne, Jonathan F. received over four thousand citations. Thus, the citations of the works of these researchers have shown that they are important sources on which exceptional studies are based. However, the findings regarding the most cited author in this study contradict Tosun's (2022) findings. Tosun (2022) found that the most cited authors were Lederman, Norman G., Treagust, David F., and Abd-el-khalick, Fouad. The reason for this difference may be that this study conducted trend analysis in six science education journals indexed in SSCI Q1, while Tosun (2022) analysed a larger data set by analysing trends in a total of 14 selected journals indexed in SSCI all quartile categories. It was found that some authors received a high number of citations despite a low number of publications. This finding may be due to the fact that people with few publications and high citations may have studied the dominant topics. For example, Tsai, Chin-Chung received 3,381 citations with 72 publications, while Abd-el-khalick, Fouad received 2,011 citations with 32 publications.

The research with high citation counts is highly influential and reflects the most influential topics (Martin-Martin et al., 2017). The most influential document in this study is the study on using Cronbach's alpha in science education, written by Taber (2018). This document has received 4,345 citations in the very short time since it was written. It is a groundbreaking work in terms of science education research methodology because the article examines research that develops and reports on research instruments. This study provides insight into the authors' interpretation of this statistic, as Cronbach's alpha is one of the most common methods used to demonstrate the reliability of scales used in studies. The fact that this study was highly cited may indicate that the use of statistical research methods in science education has increased in recent years. After Taber (2018), the most influential documents are the works of Hofstein and Lunetta (2004) and Carlone and Johnson (2007), which received 1,000 or more citations. Hofstein and Lunetta (2004) addressed the fundamentals of laboratory use in science education in a 21st-century context. In their study, they provided insights into how to improve teachers' laboratory goals in science education and how to assess students' laboratory practice processes and assessments. Carlone and Johnson (2007) developed a science identity model to understand the science experiences of 15 accomplished women. The results of this study reveal striking implications for theoretical concepts of science identity and women of colour’s experience of science culture.

The focus of highly cited studies has changed over time. For example, highly cited studies focused on argumentation in 2003-2007 (Lee et al., 2009), argumentation, inquiry-based learning, and scientific modelling in 2008-2012 (Lin et al., 2014), and inequality in science education, STEM education, and undergraduate research experiences in 2013-2017 (Lin et al., 2019). The highly cited articles in this study are evolutionarily similar in the sense that their research topics bear traces of the most cited studies in previous studies in specific periods. The highly cited articles in this study between 2004 and 2024 include assessment (number 1), laboratory (number 2), science identity (number 3), research experiences (number 4 and 6), argumentation (number 5), scientific inquiry (number 7), augmented reality (number 8), scientific modelling (number 9), and computational thinking (number 10) as topics (see Table 3).

Tsai and Wen (2005) reported that learners’ conceptions and conceptual change were prevailing themes in science education between 1998 and 2002, and the interest shifted slightly to learning contexts and social, cultural and gender issues. It was reported that the prevailing themes in science education between 2003 and 2012 shifted to learning contexts compared to 1998-2002 (Lee et al., 2009; Lin et al., 2014). Lin et al. (2019) emphasized that although students' learning contexts, science teaching, and conceptual learning were the most studied topics in 2013-2017, research on this topic has decreased compared to previous years. As a result of the present study, it was found that past topics such as laboratory, socio-scientific issues, inquiry, nature of science, conceptual change and argumentation are still being studied as found in previous studies (Lee et al., 2009; Lin et al., 2014; Lin et al., 2019; Tosun, 2022; Wang et al., 2023). Similar to the findings of Tosun's (2022) study between 1982 and 2021, the prevailing themes in this study were scientific reasoning, scientific inquiry, teacher education, conceptual change, and STEM education. There is no doubt that the research topics of science education researchers have changed, especially in the studies from COVID-19 to the present (2019 to 2024). In the SSCI Q1 journals and the 2004-2024 timeline, emerging areas of interest include computational thinking, artificial intelligence, systems thinking, engineering education, online education, science identity, and gender issues, as well as ethnicity, diversity, equity, minority, and marginalized groups. STEM education represents a prevailing theme that has been extensively studied in the past and continues to attract scholarly attention.

Undoubtedly, one of the most important findings of this study is that research on online education and technology has increased in the post-COVID-19 period. This finding suggests that the pandemic has shifted priorities in science education toward an increased emphasis on digital tools. This finding may be because technology integration in science education is an emerging area of interest (Stevenson et al., 2017). The shift towards technology in post-COVID-19 science research trends may be due to the obligation for researchers and educators to explore digital learning in depth (Pokhrel & Chhetri, 2021) and to prepare learners for a changing world as technological developments, such as the use of artificial intelligence, accelerate in the 21st century (Pedro et al., 2019). As the use of artificial intelligence (AI) in education is relatively new, it should be considered that it may bring various challenges. Teachers' lack of AI literacy, limited knowledge and experience of AI applications are points that need to be improved. Although the use of artificial intelligence in science education poses various challenges, the use of artificial intelligence in the classroom brings various innovations. For example, AI tools like ChatGPT can provide students with personalized learning experiences.

STEM education is a prevailing theme may be due to the preparation and implementation of curriculum materials for STEM education, as it is constantly evolving (Martín-Páez et al., 2019; Wang et al., 2023). In addition to STEM education, gender and career interest and science identity are emerging areas of interest as low levels of career interest in general and female representation in STEM fields are still the main challenges for STEM researchers, educators and policymakers (NCSES, 2023; WISE, 2023), which leads to researchers to investigate underlying factors for STEM career interest (e.g., Balta et al., 2023; Dabney et al., 2012; Yerdelen-Damar et al., 2024) and to develop interventions aiming equality for minorities (e.g., Todd & Zvoch, 2019; Wade-Jaimes et al., 2021). Science identity is one of the leading factors influencing students' career interests, especially females' (Zhao et al., 2024). Although gender equity in STEM education presents several challenges in practice, it is an important area for orienting underrepresented groups and achieving career goals through various STEM projects.

Another emerging area of interest is systems thinking. Recent systematic literature reviews have reported an increase in the number of publications on systems thinking in science education in recent years (Budak & Ceyhan, 2024). Systems thinking may have influenced an emerging area of interest in science education, as it positively impacts understanding of scientific concepts (Vachliotis et al., 2014) and allows them to take a holistic view of a complex topic such as socio-scientific issues (Delaney et al., 2021).

Wang (2023) found that although scientific argumentation has been studied for years, it has also been studied more extensively in recent years. This finding of Wang (2023) is different from the findings of this study because this study did not find scientific argumentation to be a topic that has been studied in recent years; on the contrary, it found STEM, technology, and systems thinking to be predominantly studied. This difference may be due to methodological differences in the studies, scope of journals, or changing research priorities.

The results of this study, consistent with the findings of other studies (Lee et al., 2009; Lin et al., 2014; Lin et al., 2019; Tsai & Wen, 2005; Tosun, 2022; Wang et al., 2023), showed that the USA contributes the most to scientific knowledge in terms of both the number of publications and citations in science education research. This finding provides clear evidence in the literature that the USA has dominated scientific research for many years. This may be due to government support for researchers, academic collaborations, and the ability to attract international researchers through grants such as the National Science Foundation (NSF) and Fullbright scholarships. However, these findings should be interpreted in the context that the journals selected for this study are all in English and USA, England and Australia are English-speaking.

In this study, Michigan State University, National Taiwan Normal University, and the Weizmann Institute of Science are the leading institutions by total number of publications. Similar to the findings of Tosun (2022) and Wang et al. (2023), the most productive institute was found to be Michigan State University in this study. Tosun (2022) placed the second and third leading institutes as the University of Michigan and the University of Illinois, while Wang et al. (2023) placed the third leading institute as the University of Michigan, which differs from the results of the present study. The result of the study reveals that the leading institutions by number of citations were Michigan State University, Indiana University, and the Weizmann Institute of Science. Similar to the findings of Wang et al. (2023), the most cited institution in this study was Michigan State University. Wang et al. (2023) also ranked the second and third most cited institutions as Kings Coll London and Indiana University, which differs from the results of the present study.

This study found that Tsai Chin-Chung, Krajcik Joseph S., Jones Melissa Gail, Sadler Troy D., and Treagust David F. were the most collaborative authors, consistent with the findings of Wang et al. (2023). International collaborations can influence the quality or focus of science education research. For example, it was found that Tsai Chin-Chung is one of the most collaborative authors, and Chin-Chung established a collaboration with Chang, Hsin-Yi, Wu, Hsin-Kai, and Chen, Sufen, and worked on technology in education. This collaborative network can contribute to the technology as an emerging area of interest. It was also found that Michigan State University (USA), Indiana University (USA), National Taiwan Normal University (Taiwan), and Weizmann Institute of Science (Israel) were the most collaborative institutions. In line with the findings of Tosun (2022) and Wang et al. (2023), this study also revealed that the most collaborative country is the USA, with established research institutions collaborating more with North America and smaller network groups collaborating more with Europe.

Conclusion and Implications

Trends in science education research provide an overview of science education research by illustrating the evolution of topics and allowing them to see the gaps in the field. Unlike previous bibliometric studies (e.g., Tosun, 2022; Wang et al., 2023), this study is unique in that it extends the time period, analyses only research indexed in English-language journals in SSCI Q1, and identifies trends in studies conducted after COVID-19. This study showed trends in the top 6 science education journals indexed in SSCI Q1 over the last two decades (2004-2024), including five-year trends, especially after COVID-19. This study revealed that interests in scientific inquiry, teacher education, conceptual change, argumentation, and socio-scientific issues in the pre-COVID-19 periods shifted to systems thinking, equity, gender, science identity, engineering education, computational thinking, online education after COVID-19.

This study has important implications for science researchers, curriculum developers, science educators, and education policymakers. The first implication of this study is to highlight that the prevailing themes in scientific reasoning, scientific inquiry, teacher education, conceptual change, and STEM education from the COVID-19 era to the present day offer different insights for science researchers. In addition, the emerging areas of interest, such as artificial intelligence, systems thinking, online education, science identity, and gender issues, will provide direction for new scholars and allow them to identify research gaps.

The second implication of this study is for curriculum developers to put research findings into science curricula. This study found that the trending pedagogical approaches are STEM education, scientific inquiry, argumentation, and laboratory, while the emerging pedagogical approaches is systems thinking. The changing interest in pedagogical approaches in science education provides revolutionary insights for curriculum designers. In STEM education, it is important for students to synthesise their knowledge from science, technology, engineering, and mathematics disciplines and to look at things from an interdisciplinary perspective (Bene et al., 2021). Therefore, in light of the findings of this study, curriculum developers should pursue avenues to tailor curricula to student diversity rather than uniform classrooms and provide science educators with possible challenges and potential suggestions. To integrate STEM education into the curriculum, curriculum developers can use the problem-based learning (PBL) approach, which allows students to connect to the real world. In addition, technology integration in science education can provide a more in-depth and experiential approach to science topics through simulations and virtual laboratories.

Systems thinking is a current pedagogical approach that allows students to approach complex problems, such as environmental issues and socio-scientific issues, from a holistic view of the structure and function of the system rather than its parts (e.g., Delaney et al., 2024). Curriculum designers should study these current pedagogical approaches and seek to integrate them into science curricula so that students can become systems literate. To integrate systems thinking into the curriculum, curriculum designers should include conceptual maps that facilitate a holistic view of complex issues such as climate change, allowing students to see the relationships between variables within the system. In addition, incorporating scenario-based learning into the curriculum can enable pupils to analyse multiple systems issues (e.g., economic, social, and environmental dimensions of sustainability) in a single scenario and provide actionable solutions to address them.

The third implication of this study is for science educators to put research findings into practice. Science educators should prepare materials and design lessons in a way that is appropriate for STEM education, considering ethnicity, diversity, equity, minority and marginalised groups. For this reason, science educators should follow current research on STEM education and diversity and educate themselves about the challenges and potential solutions to these challenges. On the other hand, science educators should also strive to educate their students as technologically literate individuals worthy of 21st-century global citizenship. Science educators should look for ways to integrate artificial intelligence into their lessons.

The fourth implication of this study is for educational policy makers to incorporate the research findings into educational policy. Education policymakers should support the practical application of scientific research by providing adequate financial support. For example, classrooms should be equipped with tools and well-trained science teachers to enable STEM and technology-integrated education. Science educators may face difficulties with ethnic and minority groups regarding theoretical knowledge and lack of practice in implementing STEM education in their classrooms. Therefore, education policy makers should not leave science educators alone in this regard and should provide them with professional development programmes in cooperation with universities. The final implication is that science researchers, curriculum developers, science educators, and education policymakers should work collaboratively to improve science education worldwide and seek ways to provide students with scientific inquiry skills, which are the most fundamental goals of science education, while considering classroom diversity.

While this scientific study has significant implications, it should be acknowledged that it has some limitations. The limitations should be considered when interpreting the results of this study. First, the database from which this study was obtained is a single data source, namely WoS. Therefore, we suggest that future studies include databases such as Scopus, ERIC, EBSCO, and Google Scholar for a more comprehensive trend analysis. A second limitation is that the journals included in this study are from the SSCI Q1 category and, non-English journals are excluded. The result of this study should be interpreted in the context of SSCI Q1 and English journals in the WoS database, which limits the generalizability of the results of this study. All SSCI categories can be included in the analysis to provide an overview of science education in future research. In addition, ESCI journals can be included in the analysis because they are also emerging sources. The third limitation is that only English-language journals are included in this study. To see trends in non-English journals, non-English journals can also be included in the analysis, and authors from different countries can collaborate for this purpose. The fourth limitation is that the publication trend analysis is based on the year of publication, which may not accurately reflect the year in which the research was conducted. There can be a considerable delay between a paper being accepted and appearing in a journal, meaning that two papers published in the same year may have been carried out several years apart. The fifth limitation is that the dataset in this study includes studies from the last twenty years (2004-2024), which means that the analysis was conducted with limited data. Therefore, future studies can analyse trends in science education over a more extended period.

References

Abd-El-Khalick, F., BouJaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., Niaz, M., Treagust, D., & Tuan, H. (2004). Inquiry in science education: International perspectives. *Science Education*, *88*(3), 397–419. https://doi.org/10.1002/sce.10118

Abdullah, K. H. (2022). Publication trends in biology education: A bibliometric review of 63 years. *Journal of Turkish Science Education*, *19*(2), 465-480. https://doi.org/10.36681/tused.2022.131

Abdullah, K. H., Roslan, M. F., Ishak, N. S., Ilias, M., & Dani, R. (2023). Unearthing hidden research opportunities through bibliometric analysis: A review. *Asian Journal of Research in Education and Social Sciences*, *5*(1), 251-262. https://doi.org/10.55057/ajress.2023.5.1.23

Amiruddin, M. Z. B., Samsudin, A., Suhandi, A., Coştu, B., & Prahani, B. K. (2025). Scientific mapping and trend of conceptual change: A bibliometric analysis. *Social Sciences & Humanities Open*, *11*, 101208. https://doi.org/10.1016/j.ssaho.2024.101208

Anwar, S., Menekse, M., Guzey, S., & Bryan, L. A. (2022). The effectiveness of an integrated STEM curriculum unit on middle school students' life science learning. *Journal of Research in Science Teaching*, *59*(7), 1204-1234. https://doi.org/10.1002/tea.21756

Archer, L., Dewitt, J., & Osborne, J. (2015). Is science for us? Black students' and parents' views of science and science careers. *Science Education*, *99*(2), 199-237. https://doi.org/10.1002/sce.21146

Balta, N., Japashov, N., Mansurova, A., Tzafilkou, K., Oliveira, A. W., & Lathrop, R. (2023). Middle- and secondary-school students' STEM career interest and its relationship to gender, grades, and family size in Kazakhstan. *Science Education*, *107*(2), 401–426. https://doi.org/10.1002/sce.21776

Bayani, F., Rokhmat, J., Hakim, A., & Sukarso, A. A. (2025). Research trends in analytical thinking skills for science education: Insights, pedagogical approaches, and future directions. *International Journal of Ethnoscience and Technology in Education*, *2*(1), 129-157. https://doi.org/10.33394/ijete.v2i1.14142

Bene, K., Lapina, A., Birida, A., Ekore, J. O., & Adan, S. (2021). A Comparative study of self-regulation levels and academic performance among STEM and non-STEM university students using multivariate analysis of variance. *Journal of Turkish Science Education*, *18*(3), 320-337. https://doi.org/10.36681/tused.2021.76

Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education*, *94*(5), 765-793. https://doi.org/10.1002/sce.20402

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education*, *93*(1), 26-55. https://doi.org/10.1002/sce.20286

Birkle, C., Pendlebury, D. A., Schnell, J., & Adams, J. (2020). Web of science as a data source for research on scientific and scholarly activity. *Quantitative Science Studies*, *1*(1), 363–376. https://doi.org/10.1162/qss_a_00018

Britner, S. L., & Pajares, F. (2006). Sources of science self-efficacy beliefs of middle school students. *Journal of Research in Science Teaching*, *43*(5), 485-499. https://doi.org/10.1002/tea.20131

Bretas, V. P., & Alon, I. (2021). Franchising research on emerging markets: Bibliometric and content analyses. *Journal of Business Research*, *133*, 51-65. https://doi.org/10.1016/j.jbusres.2021.04.067

Budak, U. S., & Ceyhan G. D. (2024). Research trends on systems thinking approach in science education. *International Journal of Science Education*, *46*(5), 485-502. https://doi.org/10.1080/09500693.2023.2245106

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187-1218. https://doi.org/10.1002/tea.20237

Carpi, A., Ronan, D. M., Falconer, H. M., & Lents, N. H. (2017). Cultivating minority scientists: Undergraduate research increases self-efficacy and career ambitions for underrepresented students in STEM. *Journal of Research in Science Teaching*, *54*(2), 169-194. https://doi.org/10.1002/tea.21341

Chabalengula, V. M., & Mumba, F. (2017). Engineering design skills coverage in K-12 engineering program curriculum materials in the USA. *International Journal of Science Education*, *39*(16), 2209-2225. https://doi.org/10.1080/09500693.2017.1367862

Chang, Y. W., Huang, M. H., & Lin, C. W. (2015). Evolution of research subjects in library and information science based on keyword, bibliographical coupling, and co-citation analyses. *Scientometrics*, *105*(3), 2071–2087. https://doi.org/10.1007/s11192-015-1762-8

Chen, C., Doyle, J., Sonnert, G., & Sadler, P. M. (2024). Shrinking gender gaps in STEM persistence: A ten-year comparison of the stability and volatility of STEM career interest in high school by gender. *International Journal of Science Education*, 1-21. https://doi.org/10.1080/09500693.2024.2388880

Chen, M., & Du, Y. (2016). The status of open access library and information science journals in SSCI. *The Electronic Library*, *34*(5), 722-739. https://doi.org/10.1108/EL-05-2015-0070

Chen, S., & Wei, B. (2022). Development and validation of an instrument to measure high school students' science identity in science learning. *Research in Science Education*, *52*(1), 111-126. https://doi.org/10.1007/s11165-020-09932-y

Christensen, D., & Lombardi, D. (2023). Biological evolution learning and computational thinking: Enhancing understanding through integration of disciplinary core knowledge and scientific practice. *International Journal of Science Education*, *45*(4), 293-313. https://doi.org/10.1080/09500693.2022.2160221

Clarivate Analytics. (2018). *Journal citation reports*. https://clarivate.com/products/journal-citation-reports/

Cooper, G. (2023). Examining science education in ChatGPT: An exploratory study of generative artificial intelligence. *Journal of Science Education and Technology*, *32*(3), 444-452. https://doi.org/10.1007/s10956-023-10039-y

Dabney, K. P., Tai, R. H., Almarode, J. T., Miller-Friedmann, J. L., Sonnert, G., Sadler, P. M., & Hazari, Z. (2012). Out-of-school time science activities and their association with career interest in STEM. *International Journal of Science Education, Part B*, *2*(1), 63–79. https://doi.org/10.1080/21548455.2011.629455

Delaney, S., Donnelly, S., Rochette, E. & Orgill, M. (2024). A system mapping activity to visualize lithium's interconnectedness to societal and environmental aspects of the green energy transition. *Chemistry Teacher International*, *6*(2), 149-163. https://doi.org/10.1515/cti-2023-0051

Delaney, S., Ferguson, J. P., & Schultz, M. (2021). Exploring opportunities to incorporate systems thinking into secondary and tertiary chemistry education through practitioner perspectives. *International Journal of Science Education*, *43*(16), 2618-2639. https://doi.org/10.1080/09500693.2021.1980631

Demir, E. (2022). An examination of high school students critical thinking dispositions and analytical thinking skills. *Journal of Pedagogical Research,* *6*(4), 190-200. https://doi.org/10.33902/jpr.202217357

DeWitt, J., & Archer, L. (2015). Who aspires to a science career? A comparison of survey responses from primary and secondary school students. *International Journal of Science Education*, *37*(13), 2170-2192. https://doi.org/10.1080/09500693.2015.1071899

Dogan, O. K. (2021). Methodological? Or dialectical?: Reflections of scientific inquiry in biology textbooks. *International Journal of Science and Mathematics Education*, *19*(8), 1563-1585. https://doi.org/10.1007/s10763-020-10120-7

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285-296. https://doi.org/10.1016/j.jbusres.2021.04.070

Dou, R., Hazari, Z., Dabney, K., Sonnert, G., & Sadler, P. (2019). Early informal STEM experiences and STEM identity: The importance of talking science. *Science Education*, *103*(3), 623-637. https://doi.org/10.1002/sce.21499

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology*, *18*, 7-22. https://doi.org/10.1007/s10956-008-9119-1

Erduran, S., Simon, S., & Osborne, J. (2004). Tapping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education*, *88*(6), 915-933. https://doi.org/10.1002/sce.20012

Fensham, P. J. (2002). Time to change drivers for scientific literacy. *Canadian Journal of Science, Mathematics and Technology Education*, *2*(1), 9–24. https://doi.org/10.1080/14926150209556494

González-Gómez, D., Jeong, J. S., Airado Rodríguez, D., & Cañada-Cañada, F. (2016). Performance and perception in the flipped learning model: an initial approach to evaluate the effectiveness of a new teaching methodology in a general science classroom. *Journal of Science Education and Technology*, *25*, 450-459. https://doi.org/10.1007/s10956-016-9605-9

Guzey, S. S., Moore, T. J., Harwell, M., & Moreno, M. (2016). STEM integration in middle school life science: Student learning and attitudes. *Journal of Science Education and Technology*, *25*, 550-560. https://doi.org/10.1007/s10956-016-9612-x

Henderson, J., Long, D., Berger, P., Russell, C., & Drewes, A. (2017). Expanding the foundation: Climate change and opportunities for educational research. *Educational Studies*, *53*(4), 412-425. https://doi.org/10.1080/00131946.2017.1335640

Hinojosa, L., Swisher, E., & Garneau, N. (2021). The organization of informal pathways into STEM: Designing towards equity. *International Journal of Science Education*, *43*(5), 737-759. https://doi.org/10.1080/09500693.2021.1882010

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education*, *88*(1), 28-54. https://doi.org/10.1002/sce.10106

Hunter, A. B., Laursen, S. L., & Seymour, E. (2007). Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. *Science Education*, *91*(1), 36-74. https://doi.org/10.1002/sce.20173

Istyadji, M., & Sauqina (2023). Conception of scientific literacy in the development of scientific literacy assessment tools: A systematic theoretical review. *Journal of Turkish Science Education, 20*(2), 281-308 https://doi.org/10.36681/tused.2023.016

Kessler, M. M. (1962). *An experimental study of bibliographic coupling between technical papers.* Massachusetts Institute for Technology, Lincoln Laboratory.

Kiewra, K. A., & Creswell, J. W. (2000). Conversations with three highly productive educational psychologists: Richard Anderson, Richard Mayer, and Michael Pressley. *Educational Psychology Review*, *12*, 135–161. https://doi.org/10.1023/A:1009041202079

Lee, M. H., Wu, Y. T., & Tsai, C. C. (2009). Research trends in science education from 2003 to 2007: A content analysis of publications in selected journals. *International Journal of Science Education, 31*(15), 1999-2020. https://doi.org/10.1080/09500690802314876

Li, Z., Sahid, S., & Abd Majid, M. Z. (2025). Global research trends on educational investment: A bibliometric analysis. *Multidisciplinary Reviews*, *8*(1), 2025033-2025033. https://doi.org/10.31893/multirev.2025033

Lin, T. C., Lin, T. J., & Tsai, C. C. (2014). Research trends in science education from 2008 to 2012: A systematic content analysis of publications in selected journals. *International Journal of Science Education*, *36*(8), 1346-1372. https://doi.org/10.1080/09500693.2013.864428

Lin, T. J., Lin, T. C., Potvin, P., & Tsai, C. C. (2019). Research trends in science education from 2013 to 2017: A systematic content analysis of publications in selected journals. *International Journal of Science Education*, *41*(3), 367-387. https://doi.org/10.1080/09500693.2018.1550274

Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2020). Research and trends in STEM education: A systematic review of journal publications. *International Journal of STEM Education*, *7*, 1-16. https://doi.org/10.1186/s40594-020-00207-6

MacCoun, R. J. (1998). Biases in the interpretation and use of research results. *Annual Review of Psychology*, *49*(1), 259–287. https://doi.org/10.1146/annurev.psych.49.1.259

Maddens, L., Depaepe, F., Janssen, R., Raes, A., & Elen, J. (2020). Research skills in upper secondary education and in first year of university. *Educational Studies, 47*(4), 491-507. https://doi.org/10.1080/03055698.2020.1715204

Martin-Martin, A., Orduña-Malea, E., Harzing, A. W., & López-Cózar, E. D. (2017). Can we use Google Scholar to identify highly-cited documents?. *Journal of Informetrics*, *11*(1), 152-163. https://doi.org/10.1016/j.joi.2016.11.008

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education*, *103*(4), 799-822. https://doi.org/10.1002/sce.21522

Marx, W., & Bornmann, L. (2015). On the causes of subject-specific citation rates in Web of Science. *Scientometrics*, *102*, 1823-1827. https://doi.org/10.1007/s11192-014-1499-9

Mayrath, M. C. (2008). Attributions of productive authors in educational psychology journals. *Educational Psychology Review*, *20*, 41-56. https://doi.org/10.1007/s10648-007-9059-y

McFarlane, A. (2014). *Authentic learning for the digital generation: realising the potential of technology in the classroom*. Routledge.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474-496. https://doi.org/10.1002/tea.20347

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., The Prisma Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Annals of Internal Medicine, 151*(4), 264–269. https://10.7326/0003-4819-151-4-200908180-00135

National Center for Science and Engineering Statistics (NCSES). (2023). *Diversity and STEM: Women, minorities, and persons with disabilities 2023*. Special Report NSF 23-315. Alexandria, VA: National Science Foundation. https://ncses.nsf.gov/wmpd.

Ong, M., Smith, J. M., & Ko, L. T. (2018). Counterspaces for women of color in STEM higher education: Marginal and central spaces for persistence and success. *Journal of Research in Science Teaching*, *55*(2), 206-245. https://doi.org/10.1002/tea.21417

Ormanci, U., Cepni, S., Deveci, I., & Aydin, O. (2015). A thematic review of interactive whiteboard use in science education: Rationales, purposes, methods and general knowledge. *Journal of Science Education and Technology*, *24*, 532-548. https://doi.org/10.1007/s10956-014-9543-3

Orbay, M., Karamustafaoğlu, O., & Miranda, R. (2021). Analysis of the journal impact factor and related bibliometric indicators in education and educational research category. *Education for Information*, *37*(3), 315-336. https://doi.org/10.3233/EFI-200442

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994-1020. https://doi.org/10.1002/tea.20035

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, *38*, 261-284. https://doi.org/10.1007/s11165-007-9049-6

Passas, I. (2024). Bibliometric analysis: the main steps. *Encyclopedia*, *4*(2). https://doi.org/10.3390/encyclopedia4020065

Pedro, F., Subosa, M., Rivas, A., & Valverde, P. (2019). *Artificial intelligence in education: Challenges and opportunities for sustainable development.* UNESCO.

Pokhrel, S., & Chhetri, R. (2021). A literature review on impact of COVID-19 pandemic on teaching and learning. *Higher Education for the Future*, *8*(1), 133-141. https://doi.org/10.1177/2347631120983481

Rudolph, J. L. (2024). Scientific literacy: Its real origin story and functional role in American education. *Journal of Research in Science Teaching*, *61*(3), 519-532. https://doi.org/10.1002/tea.21890

Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of Research in Science Teaching*, *44*(1), 57-84. https://doi.org/10.1002/tea.20163

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, *41*(5), 513-536. https://doi.org/10.1002/tea.20009

Salvadó, Z., Casanoves, M., & Novo, M. (2013). Building bridges between biotech and society through STSE education. *The Journal of Deliberative Mechanisms in Science*, *2*(1), 62-74. https://doi.org/10.4471/demesci.2013.09

Saribas, D. (2023). An online laboratory applications course for the development of scientific practices and scientific method. *International Journal of Science Education*, *45*(16), 1340-1367. https://doi.org/10.1080/09500693.2023.2205550

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, *88*(4), 610-645. https://doi.org/10.1002/sce.10128

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., Fortus, D., Shwartz, Y., Hug, B., &Krajcik, J. S. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632–654. https://doi.org/10.1002/tea.20311

Sengul, O. (2019). Linking scientific literacy, scientific argumentation, and democratic citizenship. *Universal Journal of Educational Research*, *7*(4), 1090-1098. https://doi.org/10.13189/ujer.2019.070421

Seymour, E., Hunter, A. B., Laursen, S. L., & DeAntoni, T. (2004). Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. *Science Education*, *88*(4), 493-534. https://doi.org/10.1002/sce.10131

Stevenson, M. P., Hartmeyer, R., & Bentsen, P. (2017). Systematically reviewing the potential of concept mapping technologies to promote self-regulated learning in primary and secondary science education. *Educational Research Review, 21,* 1–16. https://doi.org/10.1016/j.edurev.2017.02.002

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education*, *48*, 1273-1296. https://doi.org/10.1007/s11165-016-9602-2

Todd, B. L., & Zvoch, K. (2019). The effect of an informal science intervention on middle school girls' science affinities. *International Journal of Science Education*, *41*(1), 102-122. https://doi.org/10.1080/09500693.2018.1534022

Tosun, C. (2024). Analysis of the last 40 years of science education research via bibliometric methods. *Science & Education*, *33*(2), 451-480. https://doi.org/10.1007/s11191-022-00400-9

Tsai, C.-C., & Wen, L. M. C. (2005). Research and trends in science education from 1998 to 2002: A content analysis of publication in selected journals. *International Journal of Science Education, 27*(1), 3–14. https://doi.org/10.1080/0950069042000243727

Trna, J., & Trnova, E. (2015). The current paradigms of science education and their expected impact on curriculum. *Procedia-Social and Behavioral Sciences*, *197*, 271-277. https://doi.org/10.1016/j.sbspro.2015.07.135

Turiman, P., Omar, J., Daud, A. M., & Osman, K. (2012). Fostering the 21st century skills through scientific literacy and science process skills. *Procedia-Social and Behavioral Sciences*, *59*, 110-116. https://doi.org/10.1016/j.sbspro.2012.09.253

Vachliotis, T., Salta, K., & Tzougraki, C. (2014). Meaningful understanding and systems thinking in organic chemistry: Validating measurement and exploring relationships. *Research in Science Education*, *44*(2),239–266. https://doi.org/10.1007/s11165-013-9382-x

Van Eck, N. J., & Waltman, L. (2023). VOSviewer manual. *Manual for VOSviewer Version 1.6.19*

Van Raan, A. F. (2014). Advances in bibliometric analysis: research performance assessment and science mapping. *Bibliometrics Use and Abuse in the Review of Research Performance*, *87*(4), 17-28.

Vijayan, S. S., & Renjith, V. R. (2021). Visualization of library and information science (LIS) journals in Scimago: an analysis of first quartile (Q1) journals. Library Philosophy and Practice. 5775, 1-15. https://doi.org/10.2139/ssrn.3885177

Wade-Jaimes, K., King, N. S., & Schwartz, R. (2021). "You could like science and not be a science person": Black girls' negotiation of space and identity in science. *Science Education*, *105*(5), 855-879. https://doi.org/10.1002/sce.21664

Wang, S., Chen, Y., Lv, X., & Xu, J. (2023). Hot topics and frontier evolution of science education research: A bibliometric mapping from 2001 to 2020. *Science & Education*, *32*(3), 845-869. https://doi.org/10.1007/s11191-022-00337-z

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology*, *25*, 127-147. https://doi.org/10.1007/s10956-015-9581-5

WISE. (2023). Latest workforce statistics. https://www.wisecampaign.org.uk/latest-workforce-statistics-released-april-2023

Yerdelen-Damar, S., Saglam, H., & Korur, F. (2024). Factors predicting STEM career interest: the mediating role of engagement and epistemic cognition in physics. *International Journal of Science Education*, 1-45. https://doi.org/10.1080/09500693.2024.2371619

Zeidler, D. L., Sadler, T. D., Applebaum, S., & Callahan, B. E. (2009). Advancing reflective judgment through socioscientific issues. *Journal of Research in Science Teaching*, *46*(1), 74-101. https://doi.org/10.1002/tea.20281

Zhai, Y., Tripp, J., & Liu, X. (2024). Science teacher identity research: a scoping literature review. *International Journal of STEM Education*, *11*(1), 20. https://doi.org/10.1186/s40594-024-00481-8

Zhang, Y., Hu, L., Liao, S., Wang, Y., Ji, X., Liu, X., Huang, F. & Zhu, J. (2023). Bibliometric analysis of publications on enthesitis in spondyloarthritis in 2012–2021 based on web of science core collection databases. *Rheumatology International, 43*(1), 173-182. https://doi.org/10.1007/s00296-022-05227-9

Zhao, M., Ozturk, E., Law, F., Joy, A., Deutsch, A. R., Marlow, C. S., Mathews, C. J., McGuire, L., Hoffman, A. J., Balkwill, F., Burns, K. P., Butler, L., Drews, M., Fields, G., Smith, H., Winterbottom, M., Mulvey, K. L., Hartstone-Rose, A., & Rutland, A. (2024). Reciprocal associations between science efficacy, STEM identity, and scientist career interest among adolescent girls within the context of informal science learning. *Journal of Youth and Adolescence, 52*, 2254–2268. https://doi.org/10.1007/s10964-023-01868-6