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ARTICLE

Analysis of the Last 40 Years of Science Education Research via Bibliometric Methods

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Abstract

The present study aimed to reveal science education research (SER) general trends via VOSviewer version 1.6.17 software program. For this purpose, a bibliometric analysis of 13,242 articles in the Education and Educational Research (E&ER) category of Web of Science (WoS) was performed. It was found that there was a significant increase in article counts since 2007, and that the most articles were published in 2020. The first conclusion of the current research was that funding support is an important factor in SER article counts published in WoS. The bibliometric analysis results showed that the most frequently used keywords in SER articles were science education, STEM/STEM education, nature of science, assessment, professional development, science, scientific literacy, argumentation, gender, and conceptual change. Another conclusion of this study was that science education researchers' interest varied according to certain year intervals. The study revealed that the most preferred topics were nature of science and professional development during 2007–2021. Additionally, research interest in the topics of conceptual change, scientific literacy, chemistry education, and attitudes during 2007–2016 declined during 2017–2021. The top four research topics in recent years were STEM, argumentation, self-efficacy, and motivation. The countries where most publications came from were the USA, UK, Australia, Turkey, and Canada. The results of this study showed that science education researchers' interest varied according to countries. The results of the study revealed that STEM/STEM education is mostly referred to in articles from the USA, Australia, UK, Taiwan, and Canada. Additionally, while there was more interest in the nature of science in the USA, Turkey, UK, and Canada there was more interest in argumentation in the USA, Turkey, UK, and Taiwan. Additionally, this study revealed the most cited SER articles' distinctive features and strength collaborations between countries and between authors. The results provided a comprehensive review to understand the recent developments in the SER.

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1 Introduction

Researchers who are considering an academic career are expected to produce information through their scientific researches and share it with the reader. Scientists publish in order to disseminate knowledge to society and advance their academic careers. Reporting a scientific research and publishing it in scientific journals is a difficult process (McGrail et al., 2006). In this process, academics may encounter difficulties of generating innovative ideas for their careers and identifying important topics in the field (Lin et al., 2019). One of the important quality indicators of scientific articles is the journals' indexes in which it is published. Articles published in high-impact factor journals not only provide cooperation between academics, but also contribute to the development of the research field (Hensen, 2009). Novice researchers may have a limited understanding about features of important journals and current research practices of the field. Therefore, it is important to periodically and systematically examine the current state and trend of articles published in top journals of the field. The problem situation of the research is to reveal the trends of the articles published in science education journals scanned in Web of Science (WoS). Thus, it is aimed to provide awareness of science education stakeholders to the topics highlighted in science education over the years. Additionally, it is intended that researchers have a clearer perspective on the past, present, and future applications of science education research (SER).

1.1 The History of the Development of SER

Societies generally have an impact on the goals of education (Atkin & Black, 2003). The development of science education research (SER) is influenced by the developing of social and economic status of the countries. SER's development dates differ in America, Europe, and Asia. Before the 1960s, the USA was the only country to establish science education as an academic discipline, with the possibility of research study and doctoral degrees (Fensham, 2004, p.11). It does not mean that there are no research studies in science education elsewhere before then. The development of science education in Brazil coincided with the late 1960s (Villani et al., 2010). The historical development of Chinese science education dates back to 1904, when the school regulation policy was published, which integrated physics, chemistry, and nature into the school curriculum (Liu et al., 2012). However, Chinese science education has gone through some important stages after 1978 as a result of intellectual changes and international influences (Wang, 2012; Wei & Thomas, 2007). The development of SER in Taiwan was positively influenced by the rapid economic growth in the 1980s (Chiu, 2016).

The development of science education in many countries is based on a pattern that extends from school science teaching to curriculum development and from there to tertiary science education. Germany, Britain, Canada, Australia, and Israel in the 1960s; France, Malaysia, and Thailand in the 1970s; New Zealand in the 1980s; and Korea, Norway, and Spain in the 1990s are some of the countries where the pattern was occurred (Fensham, 2004, p.25). Although science education first researches began in the early twentieth century, its development gained momentum in the 1950s; especially in the 1980s, it became an increasingly developing research discipline.

1.2 Science Curriculum Reforms

Cold War that occurred after the Second World War triggered the development of SER. The participating countries made some reforms in their science education programs to win the Cold War. The main waves (basic transformations) of the 1960s, 1980s, and 2000s in science education reforms are important in the development of SER (De Jong, 2007). The first of these basic transformations began when Russia sent Sputnik into space in 1957. The quality of science education given in schools, especially in the USA and UK, began to be questioned. The revision of science teaching programs, which began especially in the USA, quickly spread to other countries of the world, and this process continued until the mid-1970s (Duit & Treagust, 1998). The first products of these large-scale reforms are known as ChemStudy in America and Nuffield in the UK. According to Sozbilir and Canpolat (2006), the common features of the science curriculum revisions carried out in many countries (e.g., USA, UK, and Australia) during this period are as follows:

- Revision of physics and chemistry courses contents
- Recognition of biology as a separate teaching field
- Highlighting research and laboratory studies in science teaching
- Beginning of science education in primary school

SER of the 1960s was on the effect of changes in teaching programs and approaches on students' science success. In this process, instead of memorizing scientific factors, understanding the basic scientific concepts and the process in science learning was emphasized (Chang et al., 2010). The most preferred research topics were misconceptions in the 1970s and conceptual change in the 1980s (Sozbilir & Canpolat, 2006). The development of research based on alternative concepts (Viennot, 1977) and conceptual change (Posner et al., 1982) in Europe and the USA provided a theoretical umbrella for many research projects.

Although the new curriculums did not provide the expected high success in science education, it contributed to the development and progress of science education in the world (Duit & Treagust, 1998). The second major transformations in science curriculum reform in the 1980s focused on that the USA is falling behind in the international economic and industrial competitions due to its weaknesses in the educational system (Chang et al., 2010). The products of these smaller-scale reforms are known as ChemCom and the British Salters' Chemistry. The second main wave emphasizes transforming the passive learning of the student at school into the active process and linking the learned scientific concepts with everyday life. This reform movement brought about change in the following issues: environmental education, science-technology-society (STS), history and philosophy of science, introduction of technology to instructional programs, and inquiry-based science education (Sozbilir & Canpolat, 2006). A third wave of science education curricula emerged in the late 1990s to solve reported difficulties (De Jong, 2007). The product of these reforms is known as Chemistry in Contexts. Interest in computer-aided teaching and learning arose between the second and third wave reforms (De Jong, 2007).

The development of science teaching programs in the world is a process that is still ongoing in different countries. Intensive studies are being done on how science education should be in the twenty-first century (Millar & Osborne, 1998). In this context, the twenty-first century science education project was implemented in the UK since 2006 (Sozbilir & Canpolat, 2006).

1.3 Theoretical Bases of SER

Learning theories are one of the most important elements determining the content of SER. Changes in learning theories are shaped by SER. Similarly, changes in research approaches are led to changes in learning theories (White, 1998). Ideas and theories related to learning from psychological studies that are not specific to science teaching and learning were borrowed during the process of developing a science curriculum. According to Fensham (2004), the following studies are important in the development of SER:

- Robert Gagne's study on hierarchical learning
- Jerome Bruner's ideas on spiral learning and his research on concept learning
- Jean Piaget's study on some basic science topics
- Henry Armstrong and John Dewey's idea of guided discovery
- Joseph Schwab's idea of teaching as inquiry
- John Dewey's special interest in science teaching in the early twentieth century
- Robert Karplus's study on the idea that science concepts are inventions, not discoveries
- Fletcher Watson's study on the historical and philosophical features of physics
- Ausubel's idea of learning by exploring science concepts
- David Hawkins' philosophical ideas

Additionally, De Jong (2007) explains the influential psychological theories in the development of science education for each wave reform as follows: (i) descriptive behaviorism (Skinner, 1953) and cognitive development (Piaget, 1954) for first wave reform, (ii) guided discovery learning (Bruner, 1966) and information-processing perspectives of learning (Gagne, 1977) for second wave reform, (iii) social constructivism (Driver, 1989) and socio-cultural perspectives (Vygotsky, 1986) for third wave reform.

1.4 Science Education as a Research Field

According to Fensham (2004), science education criteria as a research field were defined in structural, intra-research, and outcome criteria dimensions. He classifies these three dimensions' components in his book as follows: (i) The structural criteria for science education include academic recognition, research journals, professional associations, research conferences, research centers, and research training. (ii) The intra-research criteria for science education include scientific knowledge, asking questions, conceptual and theoretical development, research methodologies, progression, model publications, and seminal publications. (iii) The outcome criteria for science education include implications for practice.

There are leading science education journals around the world where science educators publish their research results. Science Education (SE), the first science education journal, was published in the USA since 1916. Additionally, the Journal of Research in Science Teaching (JRST) was published in the USA since 1963. The International Journal of Science Education (IJSE—from 1987 to current; formerly known as European Journal of Science Education—from 1979 to 1986) and Studies in Science Education (SSE—from 1974 to current) are known as science education journals published from Europe. Research in Science Education (RISE) is the official journal of the Australasian Science Education Research Association (ASERA). Well-known international SSCI-indexed other science education journals (including physics, chemistry, and biology education) were Science & Education (S&E), Chemistry Education Research and Practice (CERP), Journal of Biological Education (JBE), Journal of Baltic Science Education (JBSE), Physical Review Physics Education Research (PRPER), Journal of Science Education and Technology (JSET), Research in Science & Technological Education (RSTE), International Journal of Science and Mathematics Education (IJSME), and International Journal of STEM education

(IJ-STEM-E). Each journal provides important contributions to SER field. Additionally, there are numerous national SER journals around the world.

The National Association for Research in Science Teaching (NARST) was founded in 1928 and holds international conferences every year. The Australian Science Education Research Association was founded in 1970 as another organization and the organization changed its name to the Australasian Science Education Research Association (ASERA) 20 years later. European Science Education Research Association (ESERA) was founded in the UK in 1995 and holds a conference every 2 years. There are other regional science education organizations, such as the East Asian Science Education Organization (EASE) that was founded in 2009. Additionally, numerous national SER organizations were established around the world.

On the other hand, the first science education professorial appointments in the UK were established in the late 1960s (Jenkins, 2001). Committees/groups such as the Physical Science Study Committee, the Biological Science Curriculum Study, the Earth Science Curriculum Project, and Chemical Bond Approach were established for the development of science education. These developments in science education field (e.g., research journals, research conferences, professorial appointments, professional associations, etc.) are indicators that science education field is a discipline or research field.

1.5 Studies Related to SER Trends

As shown in Table 1, various analysis studies were conducted over the past two decades to reveal SER's trends. In the literature, revealing SER's trends was an important issue; thus, researchers attempted to examine trends and changes in SER via content analysis methods in the initial studies. The first content analysis was conducted by White (1997) to examine trends and changes in SER. Articles were divided into 10-year periods and the keywords in the articles were counted. It was reported that SER shifted from laboratory experiments to descriptions of observation and classroom practices and interviews were widely used as data collection tool.

In another study, researchers discussed problems with the use of statistically significant tests and made recommendations on how to improve the research quality of articles (Rennie, 1998). Eybe and Schmidt (2001) investigated trends in chemistry education research. In this study, the articles were examined in six categories. In analysis studies conducted to reveal changes and trends in SER, it is seen that superficial analyses such as keyword counting are performed as the number of documents increases (e.g., White, 1997), and more detailed analyses are performed as the number of documents decreases (e.g., Eybe & Schmidt, 2001).

Tsai and Wen (2005) analyzed research papers in terms of the authors' nationality, research types, and topics. They reported that although the science education researchers from the USA, UK, Australia, and Canada contributed to most of the publications, researchers from other countries whose native language was not English also had valuable contributions to the publications. This study determined that most articles were experimental, and the number of articles in the theoretical and review type was less. In a study carried out by Sozbilir and Kutu (2008), the researchers investigated SER's trends in Turkey and reported that SER in Turkey began in the 1990s, and paper numbers reached the highest number in 2005, and declined after 2006–2007. In another study, graduate theses in science education field were examined via a matrix that included topics such as years, interests, methodology, and sampling of the research (Çalık et al., 2008). In a study carried

Table 1 Studies related to SER's trends

Authors	Database/journals	Number of documents/document types	Year range	Methods used
White (1997)	RISE and ERIC	Articles	1965–1995	Content analysis
Rennie (1998)	JRST, IJSE, RISE, RSTE, and SE	Articles	Unspecified	Unspecified
Eybe and Schmidt (2001)	JRST and IJSE	81 articles	1991–1997	Unspecified
Tsai and Wen (2005)	IJSE, SE, and JRST	802 articles	1998–2002	Content analysis
Sozbilir and Kutu (2008)	28 different journals	413 papers	1990–2008	Content analysis
Çalık et al. (2008)	Thesis center	444 graduate theses	1990–2007	Matrix
Lee et al. (2009)	IJSE, SE, and JRST	869 articles	2003–2007	Content analysis
Chang et al. (2010)	IJSE, JRST, RISE, and SE	3039 articles	1990–2007	Scientometric
Sozbilir et al. (2012)	67 different journals	1249 papers	1973–2009	Content analysis
Lin et al. (2014)	IJSE, JRST, and SE	990 articles	2008–2012	Systematic content analysis
Lin et al. (2019)	IJSE, JRST, and SE	1088 articles	2013–2017	Unspecified

out by Lee et al. (2009), the researchers were a follow-up to Tsai and Wen's (2005) initial research. The results showed authors from other countries whose native language was not English published an increasing number of articles in the past decade. While the science education researchers' interests were concept learning and conceptual change during 1998–2002, it is reported that these interests shifted toward topics in the context of students' learning during 2003–2007. Additionally, this study reported that argumentation topic was received significant attention from science education researchers.

In another study, automatic content analysis was performed using scientometric methods to reveal the trends of SER (Chang et al., 2010). Scientometrics is a sub-field of bibliometrics. Such methods allow researchers to analyze a number of documents. It provides a more rational explanation of the changes and trends in the analyzed field. Researchers reported that although the number of articles slightly declined in the 2000s, conceptual change and concept maps were the most studied topics. Additionally, professional development, the nature of science, socio-scientific issues, conceptual change, and analogy attracted the attention of science education researchers over the years. In a study carried out by Sozbilir et al. (2012), the researchers examined papers published 67 different journals, including 30 national and 37 international via content analysis. In another study by Lin et al. (2014), researchers reported that the most preferred topics were students' learning, science teaching, and students' conceptual learning. Additionally, this study revealed that research topics regarding argumentation, inquiry-based learning, and scientific modeling received significant attention from science education researchers. Lastly, Lin et al. (2019) investigated SER's trends. They reported that the research topics regarding STEM education, inequality in science education, and undergraduate research experiences were gradually highlighted by science education researchers.

1.6 The Importance of the Study

The ability to predict future SER's topics depends on knowing which topics were studied in previous years of this field (Chang et al., 2010). Studies that synthesize initial researches are guided future research (Osborne, 2007). Educational policy makers are interested in the systematic review of qualitative research, secondary data analysis, and meta-synthesis studies, and these analysis studies help them plan their science education policies (Rossman & Yore, 2009). SER article counts are increasing everyday. This also brings the need for studies to help monitor developments in SER. This study aims to reveal SER's current state and to contribute to educational policy makers to create sustainable policies in science education.

The number of articles analyzing and evaluating SER is limited to the studies in Table 1 (Çalık et al., 2008; Chang et al., 2010; Eybe & Schmidt, 2001; Lee et al., 2009; Lin et al., 2014, 2019; Rennie, 1998; Sozbilir & Kutu, 2008; Sozbilir et al., 2012; Tsai & Wen, 2005; White, 1997). Some of these studies were conducted under the leadership of C.C. Tsai. Researchers analyzed SER articles published in 5-year periods between 1998 and 2017 (e.g., Lee et al., 2009; Lin et al., 2014, 2019; Tsai & Wen, 2005). The analyzed articles were published in three science education journals (IJSE, JRST, and SE). The content analysis method was mostly used in the assessment of these research and approximately 1000 articles were analyzed in each study. These assessments were made according to different criteria, especially focusing on the methodologies and topics of research. On the other hand, assessment of studies was limited to certain year intervals for reasons such as limited time, work force, and human resources. Göktaş et al. (2012) stated that this situation caused the research results to be scattered. For these reasons, an overall picture of the last 40-year history of SER could not be fully revealed. Additionally, thematic and scientometric methods were used in previous studies. Technological developments differentiated methods used to determine changes and trends in the related field. These developments allow researchers to examine more documents in less time and more details. For example, Chang et al. (2010) analyzed 3039 articles using scientometric methods. With computerized text analysis, meaningful structures are revealed among the large stack of data on the web (Salloum et al., 2018). The valuable contributions of the above-mentioned studies are not ignored. However, the evolution of science education revealed narrowly framework in these studies. In this present study, 13,242 articles published in the last 40 years of SER were analyzed via bibliometric methods.

Bibliometric analysis is different from systematic literature reviews and meta-analysis studies. In systematic literature reviews, such as content and thematic analysis, analyses are often carried out manually. In addition, since systematic literature reviews are conducted with qualitative techniques, interpretation biases of academics from different academic backgrounds could overshadow the analysis results (MacCoun, 1998). Quantitative techniques are used in meta-analysis and bibliometric analysis. While a limited number of documents are examined in systematic literature reviews, thousands of articles can be analyzed by computer techniques in bibliometric analysis. In the meta-analysis, the relationship between the variables is analyzed and the effect size of the experimental studies is revealed (Carney et al., 2011). Since the meta-analysis focuses on experimental studies, the heterogeneity of the relevant literature is less ensured. Since the diversity of the publications to be analyzed cannot be ensured, this may adversely affect the validity of the analysis results. In this study, bibliometric analysis techniques were used, not systematic literature review and meta-analysis, and it is expected that the results will make a different contribution to SER literature and reveal the overall picture. This study is the most comprehensive of the studies conducted to date to reveal the trends of SER. Unlike the relevant literature, this current study investigated distribution of the most popular keywords over the years, evolution of SER over the years, core topics that become visible over the years, and the most preferred topics by science education researchers of most productive countries. In addition, this study analyzed articles published in 14 science education journals (please see Fig. 1), and strength collaborations between countries and between authors were revealed. With this aspect, it is considered that it will fill an important gap in the SER literature.

1.7 The Aim of the Study

The aim of this study was to reveal the trends of SER articles published in SSCI journals. Keywords are article-specific terms that have the potential to reflect the research. The abstract is anatomy of a research. The abstract is an important part of the study presented in bibliographic search engines. It is the most read section after the title in an article. It is written very carefully because it is the part that is most read by readers and editors and determines the fate of the article. For these reasons, trends of keywords in SER articles and the most frequently used words in articles' abstract were analyzed.

Scientific and technological developments have the potential to change researchers' research interests. The research interests of science education researchers in the past and present facilitate the prediction of future research interests. This refers science educators to popular fields or fields of need. Additionally, field specialists are one of the accurate and reliable sources of knowledge. It is important that the most productive and most cited scientists and

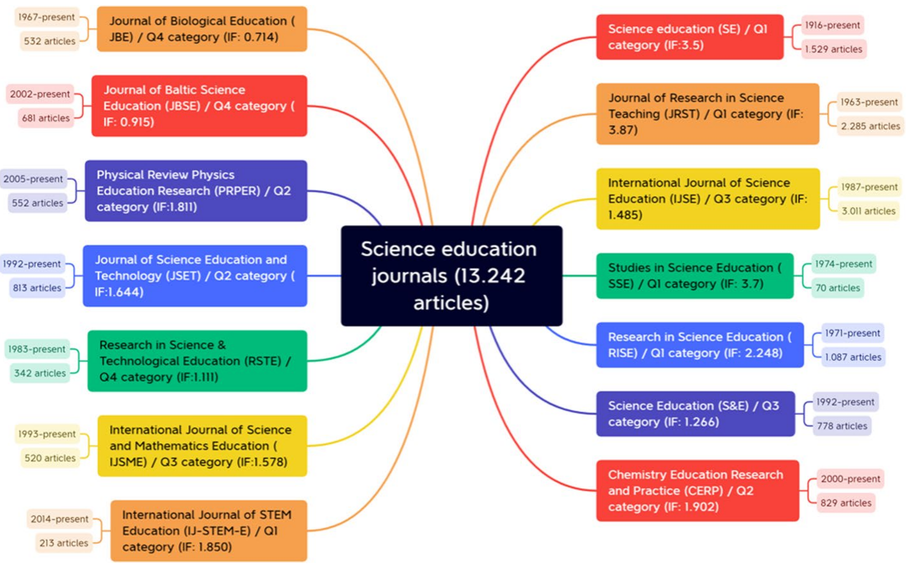

Fig. 1 Selected science education journals

collaborations between authors in science education field are known to the new researchers of this field. They have the potential to demonstrate new researchers' popular research fields. It is important to understand the educational policies that affect in this success of the most productive countries.

This study examined the most used keywords according to years and countries, the most used words in abstracts, the most productive researchers, and the most cited articles' distinctive features in SER articles. Furthermore, the study can be a useful resource for researchers in SER field by answering the following research questions:

1) What are the SER article counts over the years?
2) What are the most preferred research topics in SER articles according to the over the years and countries?
3) What is the distribution of the most frequently used words in the abstracts of SER articles?
4) Who are the most productive authors in SER articles?
5) What are the most cited articles' distinctive features in SER articles?

2 Method

Meaningless data stacks are made meaningful by certain operations using data mining methods. If the data source is texts, the processing of text stacks is classified as text mining (Artsın, 2020). Text mining is also referred to as computerized text analysis (Kobayashi et al., 2018). This study is a text mining application.

The documents were examined in the present study. A total of 13,242 articles published in selected science education journals (please see Fig. 1) were analyzed. SER article counts were increased in recent years. This brought some challenges for science education researchers. Content analysis is one of the methods used to analyze numerous publications (Falkingham & Reeves, 1998). Other methods are bibliography, scientometric method, and bibliometric analysis methods. Bibliographic studies provide information about the descriptors of publications in the relevant field for the reader. Scientometric method is a sub-field of bibliometric method. The method of bibliometric analysis is very useful (Pesta et al., 2018) and it is often used for quantitative analysis of scientific publications (Chen et al., 2016). Bibliometric methods reveal current state and future trends of research (Vogel & Masal, 2015). In this present study, the bibliometric analysis method was applied to reveal the trends of SER.

2.1 Article Selection Process

WoS database was used in this text mining application. One of the most important indicators in comparison of scientific productivity among countries is international scientific publications (Tonta, 2017). The indexes of these publications are among the quality indicators of the study. WoS consists of six online databases and one of which is SSCI. SER journals were indexed in the SSCI. The reason for selecting the WoS database is because the VOSviewer program analyzes only the WoS, SCOPUS, and PubMed database files. Analysis of articles published highly impact factor journals can help researchers recognize more effective studies in the field (Shih et al., 2008). Highly cited articles are better recognized in related fields and offer more innovation to other research (Shih et al., 2008).

SER articles were in the Education & Educational Research (E&ER) category of WoS and they were accessed using the "basic research" option in WoS database. A total of 252,948 articles appeared with the first scan. These articles were published in 406 different journals. Two hundred sixty-two of these journals were in the Q rank (quartile) categories (Journal Citation Reports [JCR], 2019). A total of 221,389 articles were published in these journals. The journals included in this study was expected to have the words "education" or "teaching," or "learning," or "instruction" and "science," or "biology" or "chemistry" or "physics" in its name. Journals that meet these criteria were determined and are presented in Fig. 1. IJSME also publishes articles in the field of mathematics education. The articles published in this journal were expected to provide the criterion that should be "science" or "chemistry" or "biology" or "physics" or "laboratory" words in topics, not "math" or "mathematics" or "mathematical" words in the title.

Figure 1 shows selected science education journals' impact factors, Q categories, and number of articles. Journals' impact factors are according to 2019 JCR. Additionally, Q categories are according to the E&ER category of WoS. CERP (829 articles), IJSE (3011 articles), JBSE (681 articles), JBE (532 articles), JRST (2285 articles), PRPER (552 articles), RISE (1087 articles), SE (1529 articles), SSE (70 articles), S&E (778 articles), JSET (813 articles), RSTE (342 articles), IJ-STEM-E (213 articles), and IJSME (520 articles) journals meet the above criteria. Later, these 14 journal names were written in the "publication name" section of the WoS and articles published in these journals were accessed. Thus, 13,242 articles published in 14 SER journals during 1982–2021 were determined (in SSCI and E&ER category of WoS; accessed, February, 2022). Article selection process is detailed in Fig. 2.

2.2 Data Editing and Analysis

Articles were recorded in “Plain Text” format with “market list” option in WoS. Files in “Plain Text” format containing information about the articles for different analyses were also recorded according to the years of publication and the addresses of the articles. These files were then uploaded to the VOSviewer. Thus, bibliometric analysis of SER articles was performed using the VOSviewer program.

Maps of distance-based, graph-based, and timeline-based approaches are used in bibliometric analysis (Van Eck & Waltman, 2014). In this study, distance-based mapping techniques were used, since the relationships between the items and the findings on the strength of the relationship were presented. Since VOS technique shows the best performance for distance-based mapping (Van Eck et al., 2008), the VOSviewer program, one of the VOS technique software, was used in the analysis of the articles.

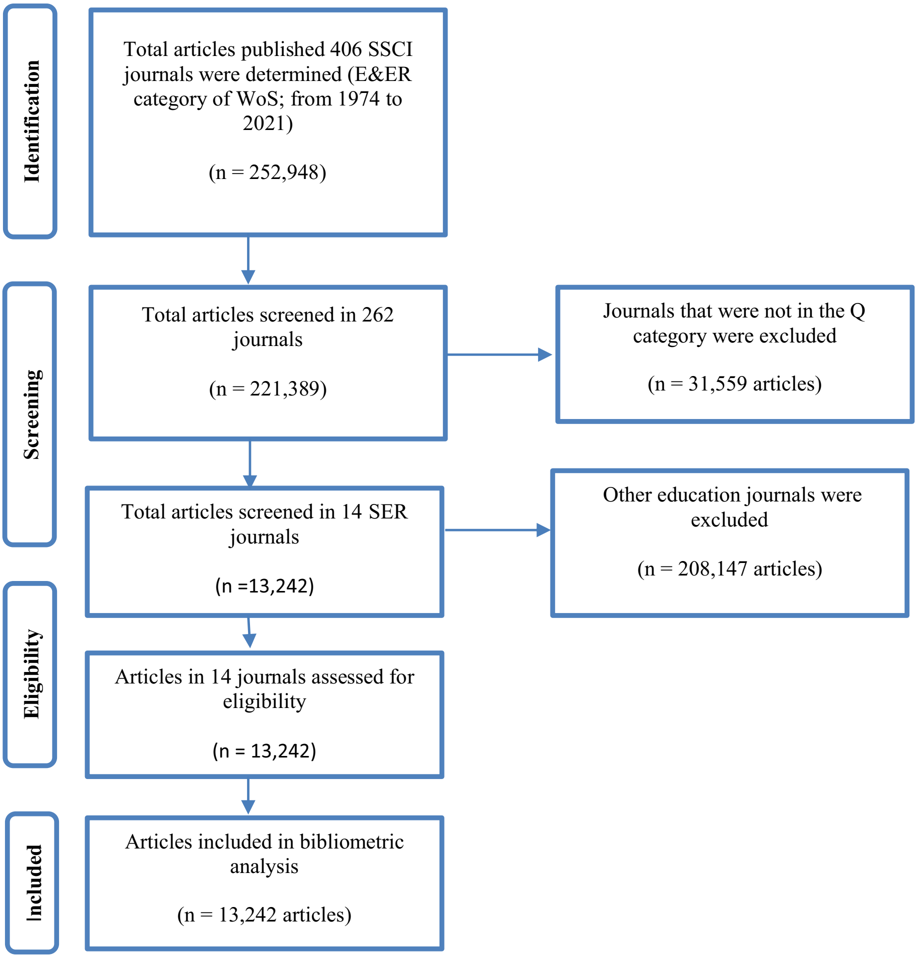

Fig. 2 Article selection process with PRISMA flow diagram (Moher et al., 2009)

In this bibliometric analysis study, the most frequently used keywords, trends of keywords by years and countries, the most frequently used words in the abstract of articles, the most productive authors and countries, the most cited authors, the most cited articles' distinctive features, and article count published over the years were revealed. The process of bibliometric analysis is summarized in Fig. 3.

Figure 3 shows that "co-occurrence" is selected as analysis type and "author keywords" is selected as analysis unit to determine the most used keywords. In order to reveal the most productive authors, "citation" is selected as analysis type and "authors" is selected as analysis unit. Additionally, first, the WoS filtering option was used to categorize researchers' interested topics by years. After, "co-occurrence" is selected as analysis type and "author keywords" is selected as analysis unit to determine the most used keywords over the years. The remaining analyses were carried out according to the steps in Fig. 3.

3 Findings

3.1 Numbers of Articles by Years

Publication and citation trends are seen as performance indicators of a discipline (Hernández-Torrano & Ibrayeva, 2020). The distribution of the number of SER articles by years is presented in Fig. 4. It is seen that the first articles were published in 1982 (in the last 40 years of SER) and the number of articles increased over the years. In 1982, 75 articles were published in the Journal of Research in Science Teaching. The number of articles, which was increasing rapidly since 2007, reached the highest number in 2020. In 2013, 674 articles were published. While 250 articles were published in 2007, 1035 articles were published in 2020.

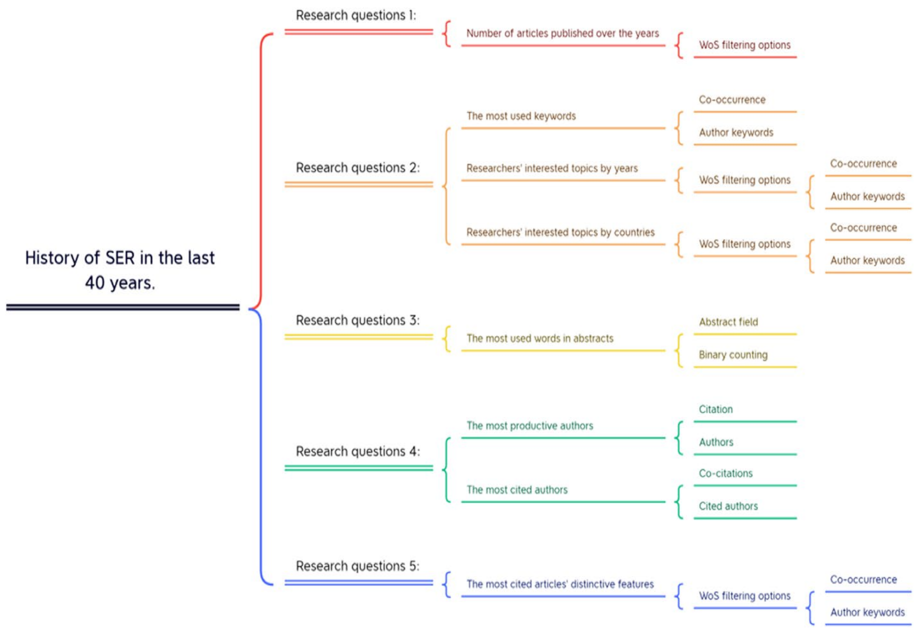

Fig. 3 Bibliometric analysis process

3.2 The Most Frequently Used Keywords in SER

The bibliometric analysis process is based on word counting. With this analysis, preferred different keywords for the same meaning or words/terms that have changed over time cannot be revealed. This situation is explained in Sect. 5 as the limitation of the study. However, to reduce this limitation, keywords used in SER articles were examined one by one and the frequencies of the keywords that are not suspected to be used in the same sense were evaluated together. In this context, "co-occurrence" was selected as the analysis type in the VOSviewer program and "author keywords" was selected as the analysis unit. The keyword's minimum repetition count was selected as 40. Thus, 85 keywords met this threshold.

The most frequently used top 10 keywords were science education ($f=658$), STEM/STEM education ($f=280$), nature of science/nature of science-NOS ($f=263$), assessment ($f=194$), professional development (f=182), science ($f=178$), scientific literacy ($f=170$), argumentation ($f=165$), gender ($f=155$), and conceptual change ($f=150$). The map formed is presented in Fig. 5. Each circle refers a keyword. The size of a circle indicates the frequency of the keyword. Clusters of keywords are represented with different colors. Lines refer to co-occurrence links between keywords and the thickness of the line refers to the strength of the relationship between them.

Five clusters appeared after the analysis. These clusters were composed of 13 to 22 keywords. The largest circle of each cluster indicates the dominant keyword. Nature of science for red cluster, science education for green cluster, science for blue cluster, attitudes for yellow cluster, and STEM/STEM education for purple cluster were dominant keywords. The word of nature of science was highly connected to the words of science education and scientific literacy. The word of science education was highly connected to the words of nature of science, professional development, conceptual change, inquiry, secondary school, attitudes, assessment, primary school, and teacher education. The word of science was highly

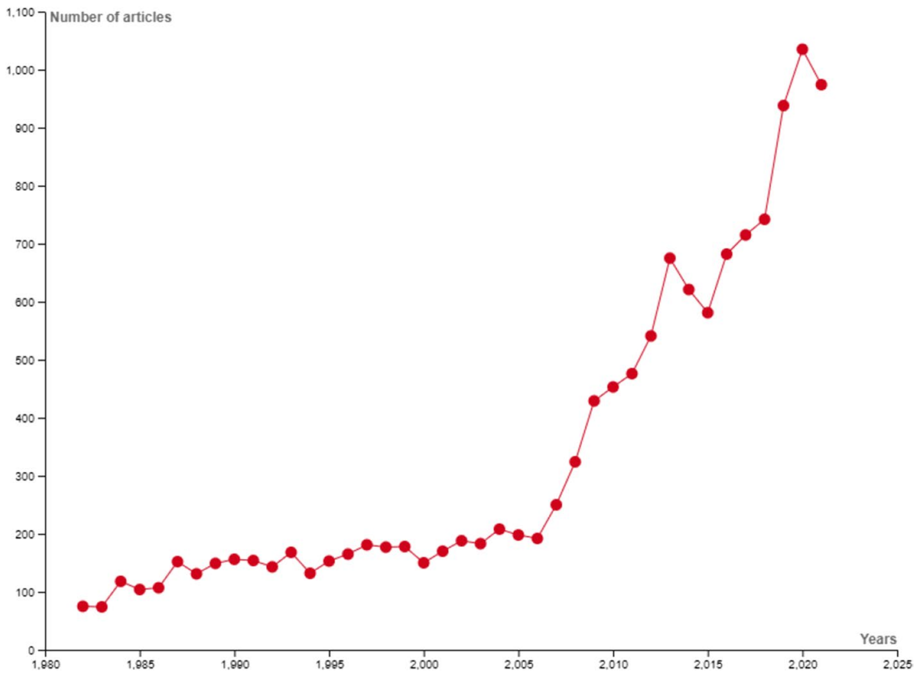

Fig. 4 Numbers of SER articles by years

connected to the words of STEM, technology, and engineering. The word of attitudes was highly connected to the words of science education, gender, and achievement. The word of STEM/STEM education was highly connected to the words of gender and science.

Core topics are presented in Fig. 6. According to this, a flow of green-yellow-orange-red was followed in the figure. Red areas show core topics, while orange areas show topics that have the potential to become core topics. According to these findings, it can be said that core topics of SER articles were science education, STEM, nature of science, science, and attitudes. The topics with the core topic potential were professional development, teacher education, pedagogical content knowledge, conceptual change, misconceptions, gender, self-efficacy, scientific literacy, and argumentation.

In this study, the most productive countries were determined using WoS filtering options. The most productive countries' article counts are presented in Table 2. The most SER articles were USA-addressed (43.50%). The contribution of eight countries to SER was 80.21% of all articles.

The most preferred topics by science education researchers in these countries are presented in Fig. 7. According to the matrix plot, the most used keyword was science education.

Figure 7 shows that professional development was among the most preferred topics in the USA- ($f=115$), Israel- ($f=14$), and Canada-addressed SER articles ($f=7$). Assessment was among the most preferred topics in the USA- ($f=111$), Germany- ($f=20$), Australia- ($f=14$), and Israel-addressed SER articles ($f=8$). This study found that one of the top topics in some productive countries was STEM/STEM education. These countries were the USA ($f=157$), Australia ($f=25$), UK ($f=19$), Taiwan ($f=8$), and Canada ($f=7$). Additionally, nature of science was among the most preferred topics in the USA- ($f=105$), Turkey- ($f=31$), UK- ($f=17$), and Canada-addressed SER articles ($f=9$). Argumentation was among the most preferred topics in the USA- ($f=78$), Turkey- ($f=26$), UK- ($f=13$), and Taiwan-addressed SER articles ($f=12$). Other topics of interest to some productive countries in science education field were attitudes (for the UK-, Australia-, Israel-, and Germany-addressed SER articles),

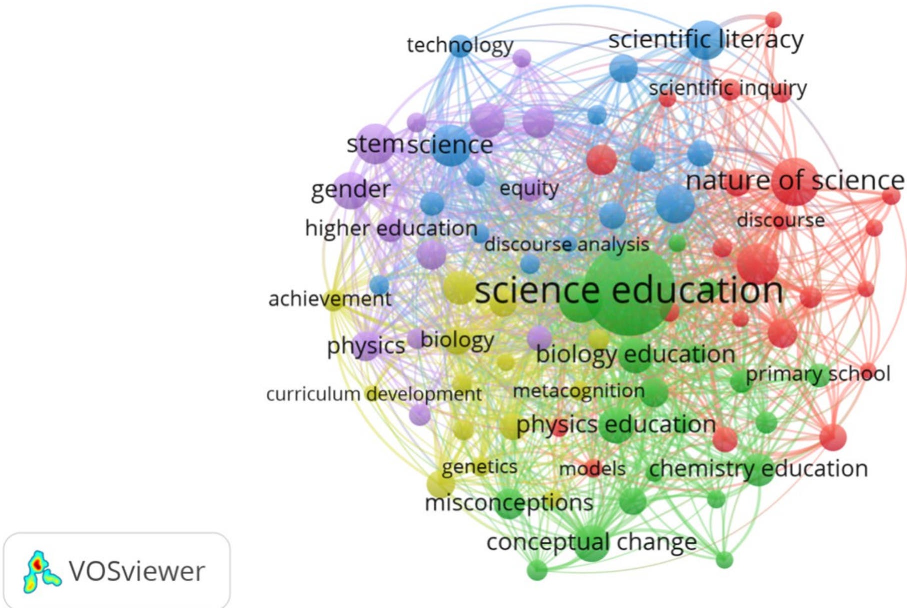

Fig. 5 The most frequently used keywords in SER articles

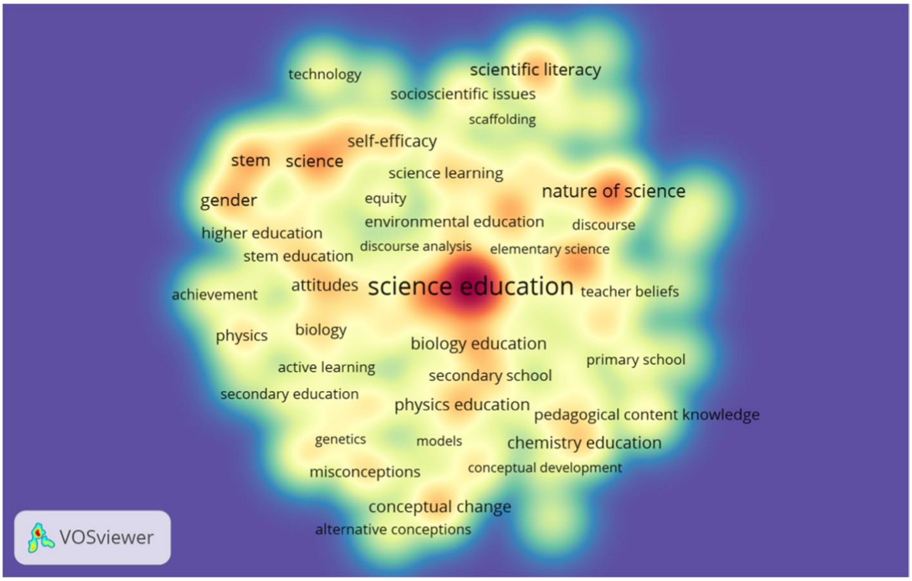

Fig. 6 Core topics of SER articles

Table 2 Number of SER articles of countries

Countries	*f*	%
USA	5768	43.50
UK	1014	7.65
Australia	941	7.10
Turkey	750	5.66
Canada	608	4.59
Israel	542	4.09
Germany	524	3.95
Taiwan	487	3.67
Total	10,634	80.21

conceptual change (for Turkey-Canada-Germany- and Taiwan-addressed SER articles), and scientific literacy (for UK-, Australia-, Canada-, and Taiwan-addressed SER articles).

Additionally, core topics for each country are presented in Fig. 8. The minimum number of occurrences of a keyword was determined as 5. The analyses resulted in 61 keywords (8 clusters) for Australia, 13 keywords (5 clusters) for Canada, 53 keywords (9 clusters) for Germany, 31 keywords (6 clusters) for Israel, 71 keywords (9 clusters) for Turkey, 47 keywords (9 clusters) for Taiwan, 57 keywords (9 clusters) for the UK, and 415 keywords (11 clusters) for the USA.

The strength of the network between the keywords was highest in the USA-addressed articles (total link strength: 7091) and least in Canada-addressed articles (total link strength: 25). Figure 8 shows that the most dominant core topic of all country-addressed SER articles was science education. Other core topics were scientific literacy, STEM/STEM education, assessment, conceptual understanding, science learning, and gender for Australia; nature of science and conceptual change for Canada; assessment, conceptual change, teacher education, attitudes, biology education, and motivation for Germany; and professional

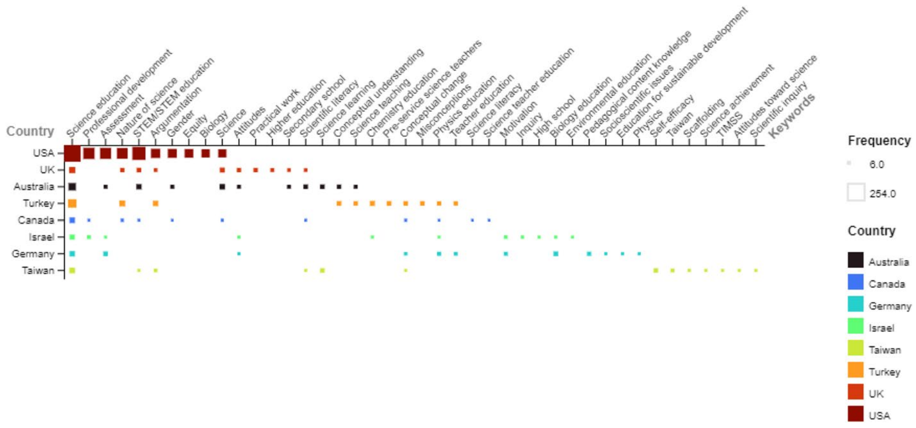

Fig. 7 The most frequently used keywords in SER by countries

development, motivation, and attitudes for Israel. Additionally, Turkey-addressed SER articles' core topics were nature of science, pre-service science teachers, conceptual change, argumentation, conceptual understanding, chemistry education, and misconceptions. Other core topics were self-efficacy, argumentation, science achievement, STEM/STEM education, eye tracking, science learning, and conceptual change for Taiwan and nature of science, STEM/STEM education, and attitudes for the UK. Lastly, USA-addressed SER articles' core topics were nature of science, STEM/STEM education, assessment, argumentation, and professional development.

On the other hand, the most preferred topics in SER articles were examined by years and the results are presented in Fig. 9.

The alluvial diagram displays the changes in the most frequently used keywords in the certain year interval. The increase in the thickness of the node means that the keyword is preferred in different year intervals. According to certain year intervals, the most frequently used keywords in SER articles were science education and assessment. The analysis results showed that the most preferred topics were peer review ($f=11$), science education ($f=9$), science teaching ($f=6$), assessment ($f=6$), conceptual change ($f=6$), classification ($f=6$), and science learning ($f=6$) during 1982–2006; nature of science ($f=234$) and professional development ($f=180$) during 2007–2021; chemistry ($f=42$), inquiry ($f=34$), misconceptions ($f=34$), and biology ($f=40$) during 2007–2011; and science ($f=65$), physics education ($f=51$), and biology education ($f=46$) during 2012–2016. Additionally, research interest in the topics of conceptual change ($f=101$), scientific literacy ($f=117$), chemistry education ($f=82$), and attitudes ($f=90$) during 2007–2016 declined during 2017–2021. Research interest in the topic of gender during 1982–2006 increased again during 2017–2021. On the other hand, research interest in the topic of argumentation increased during 2012–2021. The top four research topics in recent years were STEM/STEM education, argumentation, self-efficacy, and motivation.

3.3 The Most Frequently Used Words in the Abstracts of Articles

"Abstract field" and "binary counting" were selected for analysis. The word's minimum repetition count was selected as 500. The number of words has turned out to be 110 automatically. Three clusters (red, blue, and green networks) appeared after the analysis. The map formed is

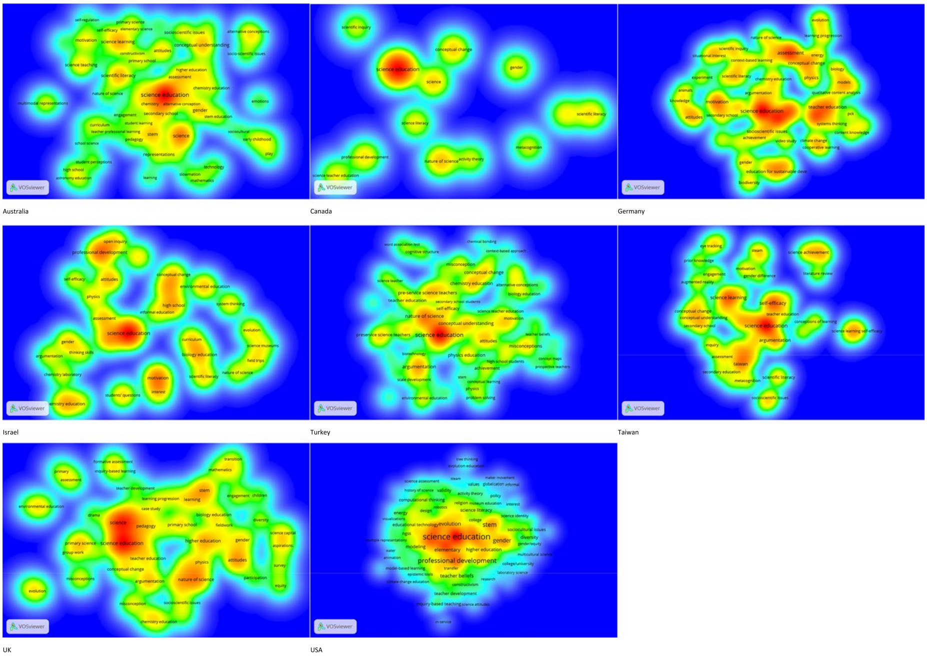

Fig. 8 Core topics for each country

presented in Fig. 10. Each cluster included a dominant word. The first cluster (red) contained 50 words and the core topic was the science (*f*=4737). The second cluster (green) contained 39 words and the core topic was student (*f*=7826). Blue cluster contained 21 words and third cluster's dominant word was understanding (3054). The word of science is highly connected to the words of science, student, teacher, learning, approach, study, development, teaching, context, knowledge, nature, activity, and practice. The word of student is highly connected to the words of study, science, level, group, difference, questionnaire, school, attitude, environment, technology, and effect. The word of understanding is highly connected to the words of study, student, concept, and model. Namely, SER articles focused on teaching or learning or practice of science concepts/activity for students in school environment. Additionally, these words can give hints of the science education researchers' research priorities and interests. According to findings, science education researchers frequently preferred nature of science, understanding the concept, and student attitudes. On the other hand, the most frequently used words in the abstracts of articles published in recent years were technology, mathematics, engineering, practice, gender, and skill. These findings confirm the findings of Fig. 9. Namely, fresh SER articles focused on STEM education, whose components are science, technology, engineering, and mathematics.

3.4 The Most Productive Authors

"Citation" was selected as the analysis type and "authors" was selected as the analysis unit. The author's minimum article counts were selected as 34 and the author's citation

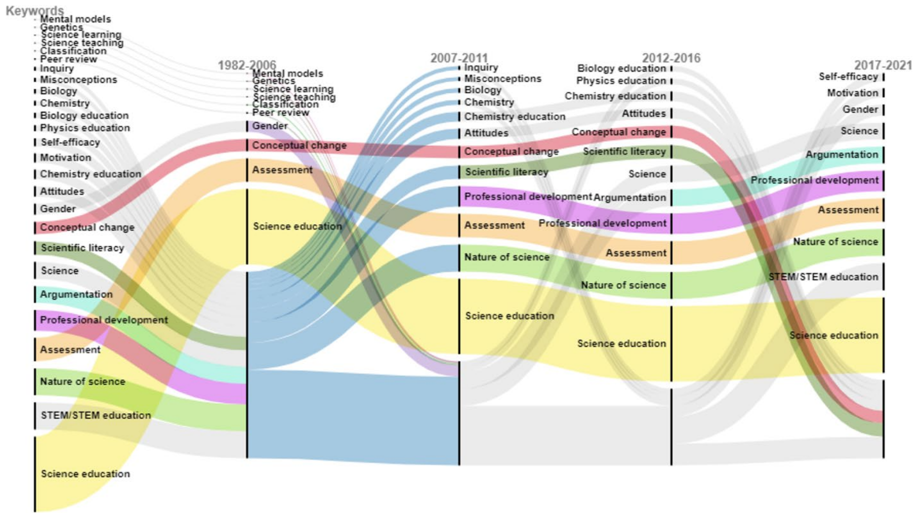

Fig. 9 Alluvial diagram for the most frequently used keywords in SER articles by years

counts were selected as 100. Eighteen science education researchers met this threshold. The most productive science education researchers are presented in Table 3. The most productive authors were W.M. Roth, D.F. Treagust, and C.C. Tsai. W.M. Roth contributed to numerous research fields. He published hundreds of articles in other journals than selected science education journals. His most cited studies were "science education for participation in the community" (Roth & Lee, 2004), "the development of science process

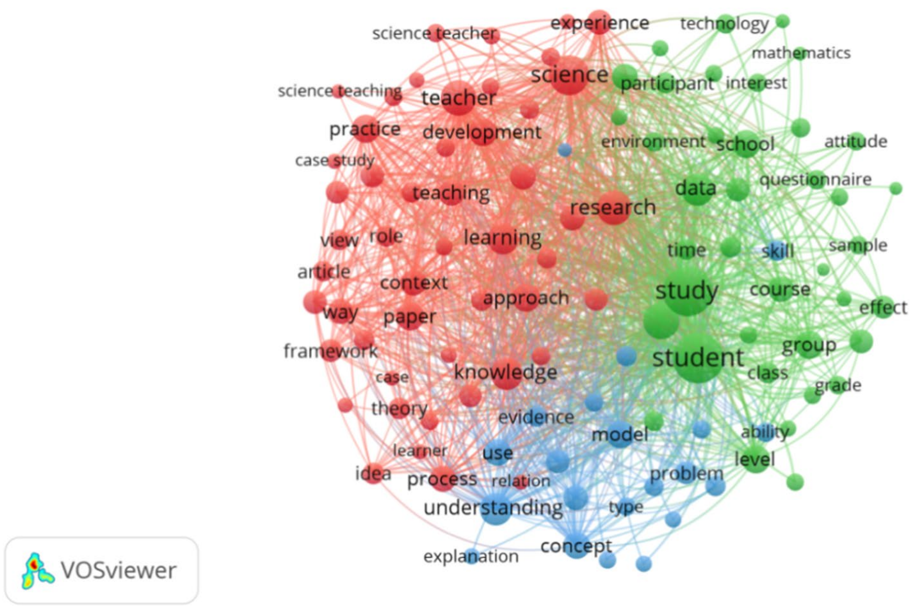

Fig. 10 The most frequently used words in the abstracts of SER articles

skills in authentic contexts" (Roth & Roychoudhury, 1993), and "physics students epistemologies and views about knowing and learning" (Roth & Roychoudhury, 1994). D.F. Treagust especially studied alternative conceptions, conceptual understanding, and students' mental models of atoms and molecules. C.C. Tsai especially studied educational technology, science teachers' beliefs, trends in science education, nature of science, and technological pedagogical and content knowledge. His most cited studies were "nested epistemologies: science teachers' beliefs of teaching, learning and science" (Tsai, 2002) and "research and trends in science education from 1998 to 2002: a content analysis of publication in selected journals" (Tsai & Wen, 2005). The most cited authors were N.G. Lederman, David F. Treagust, and F. Abd-el-khalich. N.G. Lederman and F. Abd-el-khalich especially studied nature of science. Their most cited studies were "students and teachers conceptions of the nature of science-a review of the research (Lederman, 1992)" and "views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science" (Lederman et al., 2002). D.F. Treagust's most cited studies were "conceptual change: a powerful framework for improving science teaching and learning" (Duit & Treagust, 2003) and "development and use of diagnostic-tests to evaluate students misconceptions in science" (Treagust, 1988).

Detailed analysis showed that the most used keywords in the articles by the most productive authors were assessment, argumentation, nature of science, conceptual change, scientific literacy, and professional development. These keywords provide clues about the interests and research priorities of the most productive science education researchers. According to these findings, it can be said that the research interests or priorities of the most productive science education researchers and the trends in science education are align. Additionally, it can be said that there is a moderate correlation between the most productive science education researchers and producing highly cited science education articles (please see Table 3). The reason the research priorities of the most productive science education researchers align with science education trends may be because the most productive science education researchers produce highly cited science education articles.

The link strengths between the authors are presented in Fig. 11. For this, science education researchers' minimum article count was determined as 25. W.M. Roth has the highest link strengths with K. Tobin, N.G. Lederman, and A.E. Lawson. D.F. Treagust has the highest link strengths with X.F. Liu and B. Hand. Also, C.C. Tsai has the highest link strengths with N.G. Lederman and T.D. Sadler. F. Abd-el-khalich has the

Table 3 The most productive science education researchers

Authors	Number of articles	Number of cited	Authors	Number of articles	Number of cited
W.M. Roth	92	3472	N.G. Lederman	40	5290
D.F. Treagust	91	4628	R. Tytler	39	859
C.C. Tsai	87	3012	F. Abd-el-khalich	38	3929
M.C. Linn	52	2736	J. Stewart	37	634
K. Tobin	50	1376	X.F. Liu	37	606
A.E. Lawson	47	1590	K.L. Mcneill	36	1725
M.G. Jones	46	1522	V. Talanquer	35	1242
T.D. Sadler	45	2776	K.S. Taber	34	2589
B. Hand	41	1392	H.S. Lin	34	553

highest link strengths with N.G. Lederman. Additionally, N.G. Lederman has the highest link strengths with Abd-el-khalich, C.C. Tsai, and T.D. Sadler.

Additionally, the most cited documents/authors in the bibliometric analysis articles' references were determined. For this aim, "co-citation" was selected as the analysis type and "cited authors" was selected as the analysis unit. The number of co-citation was selected as 1000. Sixteen authors/documents met this threshold. The most cited documents/authors in the bibliometric analysis articles' references were National Research Council-NRC (*f*=3772), N.G. Lederman (*f*=2126), J. Osborne (*f*=2093), W.M. Roth (*f*=1904), R. Driver (*f*=1551), K.S. Taber (*f*=1532), T.D. Sadler (*f*=1443), F. Abd-el-khalich (*f*=1405), R.A. Duschl (*f*=1307), D. Kuhn (*f*=1283), A. Bandura (*f*=1150), A.E. Lawson (*f*=1125), D. Hodson (*f*=1091), J.K. Gilbert (*f*=1082), L.S. Shulman (*f*=1073), and J.D. Novak (*f*=1014).

4 The Most Cited SER Articles' Distinctive Features

In the present study, it was found that there were 533 highly cited SER articles (accessed: February, 2022). These articles' minimum citation counts were 100. This study revealed most cited SER articles' distinctive features. The results showed that the most cited articles were published in the JRST (*f*=239 articles), SE (*f*=139 articles), and IJSE (*f*=110 articles). Additionally, the most frequently used keywords in highly cited articles were inquiry (*f*=9), science education (*f*=9), general science (*f*=8), biology (*f*=8), equity (*f*=7), attitudes (*f*=7), assessment (*f*=7), secondary (*f*=6), middle school science (*f*=6), motivation (*f*=6), professional development (*f*=6), and scientific literacy (*f*=6). On the other hand, top highly cited articles were examined in detail and it was found that research topics regarding argumentation (Driver et al., 2000; Osborne et al., 2004), motivation (Black & Deci, 2000), nature of science (Lederman, 1992; Lederman et al., 2002), inquiry (Minner et al., 2010), science experience (Carlone & Johnson, 2007), research experience (Seymour et al., 2004), and research instruments (Taber, 2018) received significant attention from science education researchers. Taber (2018) especially studied the use of Cronbach's alpha when developing and reporting research instruments in science education. This article received over 1366 citations in a short period of time (February,

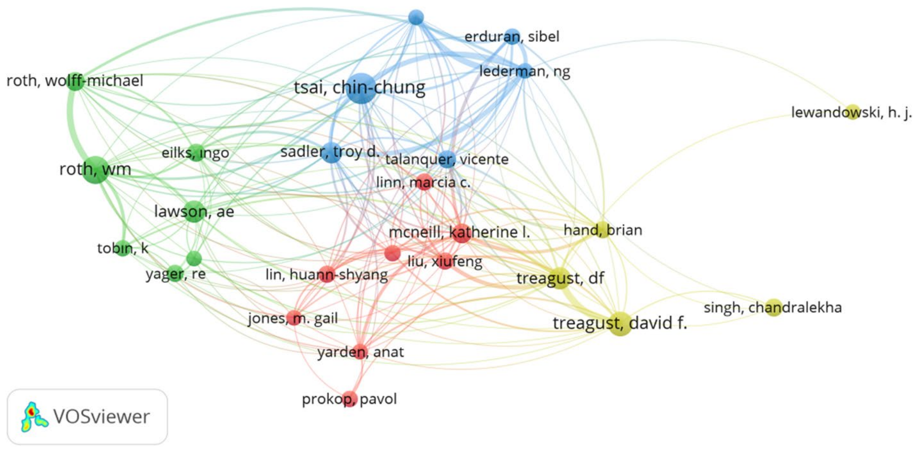

Fig. 11 The link strength between the authors

2022). Another highly cited SER article focused on the norms of scientific argumentation in classrooms (Driver et al., 2000). Black and Deci (2000) investigated the effects of instructors' support and students' motivation on learning organic chemistry. Additionally, nature of science studies (e.g., Lederman, 1992; Lederman et al., 2002) have also received much citation from science education researchers and it has been an field of productive research.

Lastly, the link strengths between the countries are presented in Fig. 12. For this, the minimum number of highly cited SER articles for a country was determined as 5. Many of the highly cited SER articles (61.2%, $f=326$ articles) were USA-addressed. Figure 12 shows that the USA has the highest link strengths with the countries of the UK (link strength: 266), Israel (link strength: 102), Australia (link strength: 94), Singapore (link strengths: 60), and Taiwan (link strengths: 57). According to the findings, it can be said that the USA is the most collaborative country in the production of highly cited SER articles.

5 Discussion and Conclusion

Francis Curtis reviewed both published and some unpublished SER studies during 1920–1937 in three periods. In the following periods, using Curtis's procedure, the researchers reviewed the selected SER studies during 1938–1957 in three periods (Boenig, 1969; Lawlor, 1970; Swift, 1969). These six periodic bibliographic reviews had SER's historical and fundamental characteristics. In later years, SER articles' trends were revealed using different methods such as content analysis, bibliography, thematic, and scientometric method (e.g., Çalık et al., 2008; Chang et al., 2010; Eybe & Schmidt, 2001; Lee et al., 2009; Lin et al., 2014, 2019; Rennie, 1998; Sozbilir & Kutu, 2008; Sozbilir et al., 2012; Tsai & Wen, 2005; White, 1997). In this present study, a bibliometric analysis of 13,242 SER articles published in 14 journals was performed. These 14 journals are indexed in SSCI and these journals are in the E&ER category of WoS. Thus, an overall picture of the last 40-year history of SER articles was revealed using bibliometric analysis methods.

5.1 Conclusions for Relationship Between Article Counts and Funding Support

The results of bibliometric analysis showed that the first SER articles in the WoS database of the last 40 years were published in 1982. The number of articles published in 1982 was 75. These articles were published in the JRST which was established 1963. This does not mean that the first SER articles were published in 1982, because SER's history goes back to the 1910s. According to the analysis results, article counts increased over years. The number of articles which was increasing rapidly since 2007 reached the highest number in 2020. SER articles' counts published annually were reached 1000 in recent years. Funding agencies were examined using the WoS filtering option and it was found that 17.9% (2381 articles) of SER articles were funded. While four articles were funded in 2007, 389 articles were funded in 2020. In another study, the researcher analyzed 93,699 educational research articles and found that the funded articles were approximately 10% of the total articles (Tosun, 2022). According to these findings, the first conclusion of the current research was that funding support is an important factor in SER article counts published in WoS. Additionally, these results showed that science education research received more funding support than other fields of education.

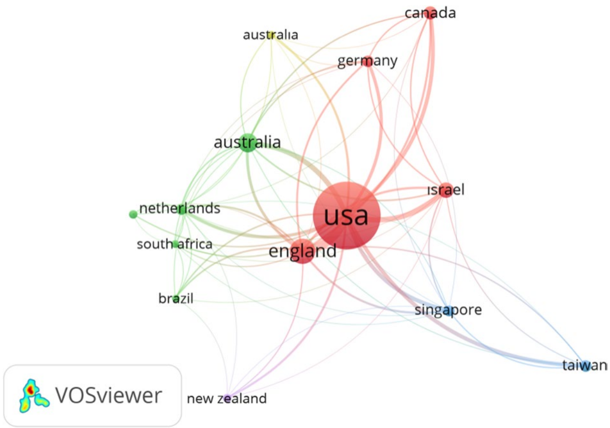

Fig. 12 The link strengths between the countries

5.2 Conclusions for the Most Preferred Topics in SER Articles

The bibliometric analysis results revealed that the most preferred topics in SER articles were the nature of science, assessment, professional development, STEM/STEM education, scientific literacy, argumentation, gender, and conceptual change. Seminal publications provide a theoretical perspective that makes sense of findings reported in initial studies, and a philosophical or epistemological framework. Additionally, these publications are a comprehensive reference point for researchers and more than a very good review or model study (Fensham, 2004). Fensham (2004) stated in his book that some studies such as historical, alternative conceptions, conceptual change, gender, and technology topics are in seminal publication status. The second conclusion of this present research was that the topics in these seminal publication status increased science education researchers' interest to these topics.

Additionally, the findings showed that five clusters appeared after the analysis and clusters' dominant keywords were nature of science, science education, attitudes, STEM/STEM education, and science. Clusters' dominant keywords were highly connected to the words of professional development, teacher education, pedagogical content knowledge, conceptual change, misconceptions, gender, self-efficacy, scientific literacy, and argumentation. In the light of these findings, it can be said that some of SER's core topics have been clarified and that it has the potential to become a core topics in some topics.

5.3 Conclusions for the Most Preferred Topics in SER Articles According to Countries

The most SER articles were eight country-addressed. These countries were the USA, UK, Australia, Turkey, Canada, Israel, Germany, and Taiwan. Of the bibliometric analyzed articles, 43.5% had addresses in the USA. One of the intra-research criteria for SER field is seminal publications (Fensham, 2004). Initiatives such as National Science Education Standard (NSES) (NRC, 1996), Project 2061 (Rutherford & Ahlgren, 1990), and Next General Science Standards (NGSS) (NGSS, 2013) focused on improving science education began in the USA and they were in seminal publication status. After that, these publications were the driving forces for SER in world-wide. USA leadership in these initiatives can be interpreted as the reason why they contribute more to SER articles. Additionally, other reasons may be that the number of universities in the USA is high, and other countries' science education researchers prefer the USA for master's, PhD, and post-doctoral studies. One of the proofs of the acceptance of science education as a research discipline is the existence of doctoral programs. The USA was the only country that established science education as an academic discipline before the 1960s, with the possibility of advanced research studies and doctoral degrees (Fensham, 2004). Additionally, the development of science education in many countries is based on a pattern that extends from school science teaching to curriculum development and from there to tertiary science education. This pattern was occurred in Germany, Britain, Canada, Australia, and Israel in the 1960s (Fensham, 2004, p.25). Another conclusion of this research was that the countries that followed this pattern in early years became the leading countries in SER article counts. The total contribution of science education researchers in the four major English-speaking countries (USA, UK, Canada, and Australia) to SER articles published during 1998–2002 was 71.7% (Tsai & Wen, 2005). This contribution rate was 62.5% during 2003–2007 (Lee et al., 2009). According to this present study's results, these four countries' contribution rate was 62.84%. In recent years, science education researchers from various countries have gradually contributed to SER field (Jenkins, 2000; Tsai & Wen, 2005). Additionally, the bibliometric analysis results showed that Turkey was ranked fourth in the ranking of the most contributing countries in SER. It was reported in the SER literature that Turkey was among the most productive top 10 countries (Chang et al., 2010; Lee et al., 2009). According to another conclusion of this comprehensive study, the contribution rates of these four English-speaking countries to SER tended to decrease with the contributions of other countries' researchers to the field.

Additionally, the most preferred topics by science education researchers in the most productive countries were determined for the first time in this study. The results of the study revealed that professional development was among the most preferred topics in the USA-, Israel-, and Canada-addressed SER articles. Also, assessment was among the most preferred topics in the USA-, Germany-, Australia-, and Israel-addressed SER articles. This study found that STEM/STEM education is mostly preferred in articles with the USA, Australia, UK, Taiwan, and Canada addresses. Additionally, while there was more interest in the nature of science in the USA, Turkey, UK, and Canada addresses' articles, there was more interest in the argumentation in the USA, Turkey, UK, and Taiwan addresses' articles. According to the countries, attitudes (UK, Australia, Israel, and Germany), conceptual change (Turkey, Canada, Germany, and Taiwan), and scientific literacy (UK, Australia, Canada, and Taiwan) were the other topics that science education researchers were interested in. Additionally, the finding showed that the strength of the network between the keywords was highest in USA-addressed articles and least in Canada-addressed articles. Two of the six categories of NSES are assessment in science education and professional development for science teachers. The emphasis of these categories in the NSES may have attracted researchers' interest in these topics. Additionally, the goal of these standards is to educate science literate individuals. Turkey's science teaching curriculum also adopts the vision of educating a science literate individual (Ministry of National Education [MoNE], 2018). According to the results of this present study, nature of science was one of the most preferred topics. The reason for the researchers' interest is that it is one of the components of science literacy. On the other hand, one of the three dimensions of NGSS is science and engineering applications. Science, engineering, and entrepreneurship practices were included in the Turkey-revised science teaching curriculum (MoNE, 2018). Thus, STEM attracted the attention of science education researchers in recent years. The development of science education in many countries was based on a pattern that extends from school science teaching to curriculum development and from there to tertiary science education. Germany, Britain, Canada, Australia, and Israel in the 1960s; France, Malaysia, and Thailand in the 1970s; New Zealand in the 1980s; and Korea, Norway, and Spain in the 1990s were some of the countries where the pattern was occurred (Fensham, 2004, p.25). The countries where the pattern early formed were the most productive countries in the SER. Another conclusion of this present study was that science researchers' interest core topics had similarities, despite the difference in their components. It can be said that the development of SER is lagging behind in countries where this pattern was occurred late. Additionally, these countries' core topics have not yet emerged.

5.4 Conclusions for the Most Preferred Topics in SER Articles According to Years

Another conclusion of this study was that science education researchers' interest varied according to certain year intervals. The study revealed that the most preferred topics were peer review, science teaching, science learning, and science education during 1982–2006; nature of science and professional development during 2007–2021; chemistry, inquiry, misconceptions, and biology during 2007–2011; and science, physics education, and biology education during 2012–2016. Additionally, research interest in the topics of conceptual change, scientific literacy, chemistry education, and attitudes during 2007–2016 declined during 2017–2021. It is reported that research interest in the topics of students' conception learning and conceptual change during 1998–2002 shifted toward topics in the students' learning context (Lee et al., 2009), social, cultural, and gender (Tsai & Wen, 2005) during 2003–2007. Chang et al. (2010) analyzed articles published in four SER journals during 1990–2007 using scientometric methods. It is reported that research interest in the topics of conceptual change and concept maps declined slightly during the 2000s, and research interest in the topics of professional development, nature of science, socio-scientific issues, conceptual changes, and analogies increased over the years. According to the results of present study, research interest in the topic of gender during 1982–2006 increased again during 2017–2021. This finding is consistent with Tsai and Wen's (2005) study results. Researchers analyzed SER articles published during 1998–2002 and found that research interest in the topic of gender increased. Additionally, research interest in the topic of argumentation increased during 2012–2021. This finding is consistent with Lin et al.'s (2014) study results. They reviewed highly cited SER articles published during 2008–2012 and found that science education researchers' interest increased in the topics of argumentation, inquiry-based learning, and scientific modeling. On the other hand, the top four research topics in recent years were STEM, argumentation, self-efficacy, and motivation. This finding is consistent with Lin et al.'s (2019) study results. They analyzed highly cited SER articles published during 2013–2017 and found that researchers gradually highlighted in the topics of STEM. Of course, science education researchers should not be expected to research the same topics. Undoubtedly, diversity has a wider and deeper impact on science education. The interest in different research topics consistent with the theoretical framework, technological developments, and the needs of society has a driving force in the development of science education. Diversity in SER can be provided by knowing the topics that researchers are interested in the past periods. It is thought that the results of this present study will be indicative for different studies in future.

5.5 Conclusions for the Most Used Words in SER Articles' Abstracts

This study was found that the most frequently used words in the abstracts of articles. Findings indicated that science, student, and understanding were dominant words used in SER articles' abstract. According to findings of most used words in abstract, SER articles focused on teaching or learning or practice of science concepts/activity for students in school environment. The results of the study revealed that student and teacher were the focus of SER. According to the results of the present bibliometric analysis, the word "student" was repeated more than the word "teacher" in the abstract of the articles. This can be interpreted as most research was conducted with students. According to findings of most used words in abstract, science education researchers' research priorities were nature of science, understanding the concept, and student attitudes. Additionally, findings indicated that fresh SER articles focused on STEM education. The results confirm the results of the most used keywords in the articles. Another conclusion of this present research was that knowing the science education researchers' interests and methods in the past and present will facilitate to predict future research interests and methods. It is expected that this result will make a different contribution, not ignoring the contribution of initial studies to the literature.

5.6 Conclusions for the Most Productive Authors

The bibliometric analysis results revealed that the most productive authors in SER articles were W.M. Roth, D.F. Treagust, and C.C. Tsai. The most cited authors were N.G. Lederman, D.F. Treagust, and F. Abd-el-khalich. Additionally, the most cited documents/authors in bibliometric analysis articles' references were National Research Council-NRC, N.G. Lederman, J. Osborne, W.M. Roth, R. Driver, K.S. Taber, T.D. Sadler, F. Abd-el-khalich, R.A. Duschl, D. Kuhn, A. Bandura, A.E. Lawson, D. Hodson, J.K. Gilbert, L.S. Shulman, and J.D. Novak. Chang et al.'s (2010) study ranked the most productive science education researchers and revealed that the most productive authors were K. Tobin, W.M. Roth, A. Barton, and M. Barnett. This result had some similarity with the results of the present study. The difference in results can be explained with the number of articles and time span. Another conclusion of this present research was that there was a moderate relationship between the most productive science education researchers and producing the highly cited science education articles. This finding is consistent with Abramo et al.'s (2014) study results.

Additionally, this study found that W.M. Roth has the highest link strengths with K. Tobin, N.G. Lederman, and A.E. Lawson. D.F. Treagust has the highest link strengths with X.F. Liu and B. Hand. Also, C.C. Tsai has the highest link strengths with N.G. Lederman and T.D. Sadler. N.G. Lederman has the highest link strengths with Abd-el-khalich, C.C. Tsai, and T.D. Sadler. Field specialists are one of the best sources of information in the relevant field. It is important for new researchers to recognize the most productive science education researchers who have made significant contributions to the field, because they help to acquire accurate and reliable information, as well as to follow popular research fields. Additionally, it is thought that the results of the study will make important contributions to international research cooperation in the field of SER.

5.7 Conclusions for the Most Cited SER Articles' Distinctive Features

Another aim in this study was to determine the most cited SER articles' distinctive features. The results of the study revealed that the most cited articles were published in the JRST, SE, and the IJSE. The top most cited articles were leading publications in the topics of argumentation, motivation, nature of science, inquiry, science experience, research experience, and research instruments. Lee et al. (2009) examined highly cited SER articles' research topics during 2003–2007 and reported that argumentation was received significant attention of science education researchers. Seminal publications are research that leads to new horizons and have the potential to form clusters in the relevant field. It is believed that it would be useful to continue the studies on these topics, since the original studies on the topics that receive the most citations have a high potential for citations. Lastly, the findings showed that the USA has the highest link strengths with the countries of the UK, Israel, Australia, Singapore, and Taiwan. Since the USA is the most collaborative country in the production of highly cited SER articles, the results of the study are thought to be important for scientists who intend to produce international joint researches and projects in the field of SER.

6 Implications

The fact that new science education researchers are aware of high-impact factor academic journals allows them to understand SER field from a broader perspective (Tsai & Wen, 2005). The most important indicator of the visibility and quality of scientific articles is that it is published in SSCI journals. In this present study, articles published in science education journals (in SSCI) were examined using bibliometric analysis method and the results of the study revealed an overall picture of the last 40-year history of SER. It is believed that the results of the study will lead to future research and will make significant contributions to science teachers, graduate students, educational administrators, and educational policy makers. It is proposed to include science education journals scanned in SCOPUS and field indexes in future studies.

The current study has some limitations. First, the results of this study are limited to articles published in SER journals during 1982–2021. Second, the study is limited to science education journals scanned in the E&ER category of the WoS and covered by the SSCI indexes. Third, science education articles published in general education journals were not included in the bibliometric analysis. Fourth, the data source of this study is texts. Analyzing text stacks according to different parameters is called text mining (Artsın, 2020). Different terms may be preferred for the same meaning. Additionally, words and terms can change over time. The text mining method is based on keyword, word, and citation counting. It can also be expressed as computerized text analysis (Kobayashi et al., 2018). For this reason, the bibliometric analysis method cannot detect keywords used in the same sense or different uses of words/terms over time. Lastly, this study differs from systematic literature reviews (e.g., content, thematic analyses) that are typically carried out manually and meta-analysis studies. Systematic literature reviews are based on qualitative techniques. This study relies on quantitative techniques such as meta-analysis. Meta-analysis studies focus on summarizing empirical evidence by analyzing the relationships between variables and the strength of the effect (Carney et al., 2011). The study's dataset is too large for manual review. Therefore, the content of the research methodologies is not suitable for manual review. This present study's findings should be interpreted within the context of these limitations.

Data Availability Not applicable.

Code Availability Not applicable.

Declarations

Ethics Approval No data was collected from human participants in the study. Research is document review. All ethical standards were taken into account and followed during the research.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The author declares no conflict of interest.

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