Journal of Pedagogical Research
Onlinefirst Article, 2025
https://doi.org/10.33902/JPR.202530575

Review Article

Trends and research frontiers in socioscientific issues for sustainable science education: A systematic and bibliometric analysis from 2014 – 2024

Zainal Arifin[1], Sukarmin Sukarmin[2] and Sulistyo Saputro[3]

[1]*Doctoral Program of Science Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia (ORCID: 0000-0002-6173-402X)*
[2]*Department of Physics Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia (ORCID: 0000-0002-3767-0660)*
[3]*Department of Chemistry Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia (ORCID: 0000-0002-5613-9496)*

This study aims to explore trends and recent developments in socioscientific issues [SSI] within the context of sustainable science education. Using bibliometric analysis with the PRISMA methodology, the study evaluates 157 articles from the Scopus and ERIC databases published between 2014 and 2024. The findings show a significant increase in the integration of SSI in science education, particularly through interdisciplinary approaches and digital technologies for real-world problem solving. The study identifies key themes science education, scientific literacy, climate change, and sustainability have become key focuses in SSI research. With an average of 15.04 citations per document, this study indicates growing academic interest and influence in this field. The findings emphasize the need for relevant curricula, teacher training, and international collaboration to advance sustainable science education.

Keywords: Bibliometric analysis; Socioscientific Issues; Sustainable science education; Systematic review

Article History: Submitted 27 August 2024; Revised 13 December 2024; Published online 28 January 2025

1. Introduction

Science education plays a fundamental role in supporting sustainable development (Husamah et al., 2022a; Ibragimov et al., 2023) and provides the necessary knowledge base to address complex global challenges (Ban & Mahmud, 2024). Science education not only facilitates conceptual understanding (Bossér & Lindahl, 2019; Nida et al., 2021) but also empowers individuals to take environmentally responsible actions (Husamah et al., 2022b; Zhdanov et al., 2023), social (Husamah et al., 2023; Klopfer & Aikenhead, 2022), and economic (Vesterinen et al., 2016) which are critical in achieving the Sustainable Development Goals [SDGs] (Cabello et al., 2024; Jackson et al., 2023).

Socioscientific issues [SSI] are problems that are rooted in science but have broad social implications (Alcaraz-Dominguez & Barajas, 2021a; Herman et al., 2022; Johnson et al., 2023). SSI in science education serves as an important tool for promoting higher order thinking skill (Kinskey & Newton, 2024; Yacoubian & Khishfe, 2018), ethical decision-making (Bader et al., 2023; Karakaya & Irez, 2022), and student engagement in meaningful discussions about real problems facing society

Address of Corresponding Author

Sukarmin Sukarmin, Department of Physics Education, Faculty of Teacher Training and Education, Jl. Ir. Sutami No. 36A, Kentingan, Surakarta, Indonesia 57126.

✉ sukarmin67@staff.uns.ac.id

How to cite: Arifin, Z., Sukarmin, S., & Saputro, S. (2025). Trends and research frontiers in socioscientific issues for sustainable science education: A systematic and bibliometric analysis from 2014 – 2024. *Journal of Pedagogical Research.* Advance online publication. https://doi.org/10.33902/JPR.202530575

(Grace et al., 2015; Zhu & He, 2022). SSI topics spanning all areas of science such as climate change (Dawson & Carson, 2020; Namdar & Namdar, 2022), biodiversity (de Freitas et al., 2023; Purwani et al., 2018), biotechnology (Eggert et al., 2017; van Lieshout & Dawson, 2016), renewable energy (Zidny et al., 2021), and public health (Powell, 2023) are all highly relevant to the SDGs.

The importance of SSI integration in science education is not only in improving scientific literacy (Bossér, 2024) but also in shaping a deeper understanding of the social implications of scientific advances and technological applications (Bay et al., 2017; Calik & Karatas, 2019). When global challenges such as climate change and biodiversity loss continue to escalate, sustainable and future-oriented science education is crucial to prepare future generations capable of facing these challenges effectively and ethically (Bencze et al., 2020; Hodson, 2020).

The serious lack of attention to the integration of SSI in science education curricula illustrates a paradox (Garrecht et al., 2023). Despite extensive research on the potential of SSI approaches, concerns are mounting about the inability of educators to prepare future generations for increasingly pressing global challenges (Büssing et al., 2020; Genel & Topçu, 2016; Leung, 2022a). There is limited research that explicitly reveals how SSI can truly transform science education and improve teachers' and students' readiness to deal with the complex issues of the 21st century.

In fact, only a few studies have addressed the critical question of how SSI can be integrated in the science curriculum in a way that encourages students to think critically and take responsibility for the future of the earth (Chen & Xiao, 2021; Karakaş, 2022; Klaver et al., 2023). This gap creates a significant knowledge gap in the science education literature that highlights a paradox between the transformative potential of SSI and the reality of their minimal implementation (Ozcan-Ermis & Hervé, 2023). Recent research suggests that there are still major challenges in integrating SSI in the science curriculum (Rasa, 2024) the need for more in-depth training for educators (Lesnefsky et al., 2023) and lack of infrastructure support (Chen & Xiao, 2021). These findings confirm that despite the drive to adopt this approach, its implementation has been uneven across different educational contexts (Lee, 2022; Valdez & Bianchini, 2023).

This systematic and bibliometric analysis aims to respond to the urgent need to fill this gap and explore current trends and research frontiers in Socioscientific Issues for Sustainable Science Education. (Lestari & Suyanto, 2024; Navas Iannini, 2023). By systematically reviewing and analyzing the literature this study aims to identify not only knowledge gaps but also great potential for change and innovation in global science education (Masalimova et al., 2024; Zulfugarzade et al., 2024).

This is the first study to systematically explore trends and research in socioscientific issues for sustainable science education. With a comprehensive approach, this study not only maps the global research collaboration network but also evaluates key contributions in the field of SSI, and identifies gaps and opportunities for further innovation in science education. As a pioneering study, the results provide strategic guidance for researchers and educators in integrating SSI into science education curricula, which is critical to achieving the Sustainable Development Goals. The study seeks answers to the following research questions:

RQ 1) How has the number of publications on socioscientific issues in science education for sustainable development changed over time?

RQ 2) What are the contributions of the most prolific authors on the subject of socioscientific issues (SSI) in science education for sustainable development?

RQ 3) Which sources are most active in producing publications on socioscientific issues in science education for sustainable development?

RQ 4) Which countries are at the forefront of research in socioscientific issues in science education for sustainable development?

RQ 5) What are the most commonly used keywords in papers on socioscientific issues in science education for sustainable development?

RQ 6) What science education subject areas receive the greatest attention in terms of socioscientific issues for sustainable development?

RQ 7) How does the distribution of publications each year change across different source fields?

2. Literature Review

Education for Sustainable Development [ESD] is an educational concept that evolved from the global awareness of the importance of maintaining environmental, economic, and social sustainability (UNESCO, 2017). Recent research shows the different ways in which ESD can be implemented and the impact it has on learners and society. The study Leicht et al. (2018) emphasizes the importance of ESD integration in higher education to equip students with the necessary skills and knowledge to address global challenges. The study found that effective ESD programs can increase environmental awareness and student engagement in sustainability issues. In addition, research by Grosseck et al. (2019) showed that the use of digital technology in ESD can improve learning effectiveness. Research by Kong et al. (2022) found that online learning platforms and other digital tools can help convey complex information and facilitate collaboration among students in sustainability projects. Lee (2022) highlighted the importance of an interdisciplinary approach in ESD emphasizing that the challenges of sustainable development are complex and require approaches involving various disciplines. The study found that educational programs that combine perspectives from science, humanities, and social sciences can be more effective in preparing students to address global issues.

But the ESD journey has not always gone well. There is a significant gap between theory and practice (Bossér, 2024). The implementation of ESD in various countries still faces various challenges, such as the lack of understanding of the concept of ESD, limited resources, and the lack of integration of ESD in the education curriculum. These challenges show the gap between the ideal vision of ESD and the reality on the ground. On the one hand, ESD is heralded as a solution to various global issues, such as climate change, poverty, and inequality. On the other hand, many educators and stakeholders still do not understand how to effectively integrate ESD into learning practices (Navas Iannini, 2023). Bridging this gap requires targeted and sustained efforts. This effort should involve various parties, including the government, educational institutions, civil society organizations, and the private sector.

Socioscientific Issues are topics that combine social and scientific aspects in a complex and controversial context (Ban & Mahmud, 2023). These issues often require moral and ethical judgment, as well as a deep understanding of the relevant science (Zeidler et al., 2019). SSI demands not only learners' cognitive ability to understand scientific concepts, but also the ability to consider the social and ethical implications of such knowledge. This is in line with the view that science education should involve values and moral dimensions, and not solely focus on cognitive aspects. Research (Khishfe, 2014) shows that teaching that integrates SSI can improve students' science literacy. This is due to increased student engagement in discussions that challenge students' critical thinking and connect science knowledge with real-world contexts (Karahan, 2022). SSI also plays a role in developing students' argumentation skills, where they are encouraged to examine multiple viewpoints and build arguments based on scientific evidence (Dawson & Venville, 2022). The integration of SSI with education often involves an interdisciplinary approach that includes science, ethics and social studies. This approach not only enriches students' understanding of complex issues but also equips them with the critical thinking skills needed to participate in discussions and decision-making related to scientific issues in society.

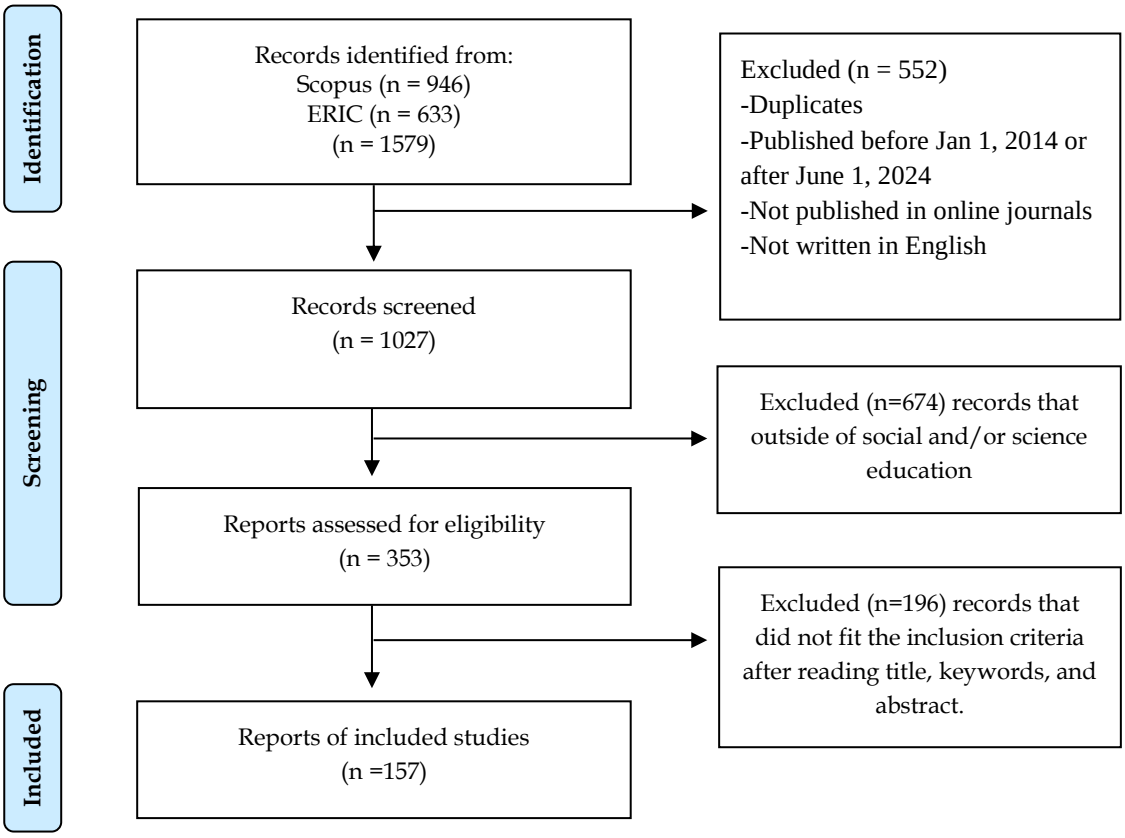
Recent research (2020-2024) has reinforced the importance of SSI in science education (Abrori et al., 2024; Gandolfi, 2024; Navas Iannini, 2023; Ram, 2020). The integration of SSI in the science curriculum can increase students' learning motivation (Itzek-Greulich & Vollmer, 2017; Levy et al., 2021) and help students develop a more holistic view of complex global issues (Herman et al., 2019; Lenhart & Bouwma-Gearhart, 2022). These studies have also found that students who engage in SSI discussions show a better understanding of how science can be applied to solve real problems (Iversen & Jónsdóttir, 2019) as well as improved critical thinking skills (Lombard et al.,

2020) and problem solving (Fadzil, 2017). Research by (Bossér & Lindahl, 2019; Tidemand & Nielsen, 2017) highlighted the importance of the teacher's role in the facilitation of SSI discussions. Teachers who have a deep understanding of SSI and are able to effectively manage class discussions can help students develop better argumentation skills (Herman, 2018)) and increase teacher and student engagement in science learning (Herman et al., 2019; Topçu et al., 2018).

3. Method

This study used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method in Figure 1 to identify, evaluate, and synthesize literature related to trends and research frontiers in Socioscientific Issues for Continuing Science Education using the steps of the bibliometric analysis process described by Pham-Duc et al. (2020) and Tuyet et al. (2024).

Figure 1
PRISMA flow diagram



3.1. Data Collection

Table 1 provides an overview of the search terms utilized in the Scopus and ERIC databases to find studies focused on socioscientific issues within the context of science education and sustainable development. The searches aimed to identify a variety of research that explored the role of SSI in science education and its impact on sustainable development.

Table 1
The specific search in the Scopus and ERIC databases

Search	*Search Term(s) in the Scopus and ERIC*
S1	TITLE-ABS-KEY (socioscientific AND issues AND science AND education) AND PUBYEAR > 2013 AND PUBYEAR < 2024
S2	"socioscientific issues" AND "science education" AND "sustainable development,"

3.2. Data Extraction

After identifying relevant sources, a selection was made by applying the pre-defined inclusion and exclusion criteria as in Table 2. These criteria included certain aspects that supported the research objectives and the defined scope of the study. The selection process was then followed by data extraction from the selected articles. Collecting relevant information related to indigenous knowledge in science education for sustainable development.

Table 2
Search keywords and inclusion/exclusion criteria

Category	*Inclusion Criteria*	*Exclusion Criteria*
Publication period	Studies published from January 2014 to June 2024	Studies published before January 2014
Language of publication	Full-text available in English	Full-text available in other languages
Study Materials	Studies published in peer-reviewed journals rated in Scimago Journal	Studies published in books, chapter or conference proceedings
Document Type	Studies conducted in science education fields	Studies outside science education (such as those in medical, nurse, therapy, rehabilitation, or gaming fields)
Subject area	Social Science	Studies outside social science (such as Business, Management, Accounting, and Linguistics)

3.3. Data Analysis

Data analysis was conducted using bibliometric methods. This includes counting the number of publications each year, keyword analysis to identify research trends, and citation analysis to evaluate the impact of research. This analysis not only provides a comprehensive picture of the current research landscape but also offers strategic insights for future research and education policy (Grosseck et al., 2019). Thematic maps and keyword clouds can be used to identify key themes and sub-themes developing in the literature on SSI. The VOSviewer (www.vosviewer.com) and Bibioshiny software (using the "bibliometrix" package of the Rstudio software to install) were used to analyze and graph the data obtained on publication networks, collaboration networks between researchers, participating organizations, main and emerging keywords in Socioscientific Issues research in sustainable science education.

3.4. Interpretation of Results

The results of the bibliometric analysis provide insights into research trends and frontiers in SSI for sustainable science education. From this analysis, we can infer key developments in the field, such as the increasing focus on student engagement in science-based decision-making and the integration of environmental issues in the science curriculum. These conclusions also help identify existing research gaps and direct future research agendas.

4. Results

4.1. The Number of Publications on Socioscientific Issues in Science Education

4.1.1. General information about socioscientific issues research publications in science education

Research on socioscientific issues in science education has become an increasingly important focus in efforts to support sustainable development. Publications in this area not only contribute to scientific understanding, but also play a key role in integrating science concepts with complex societal challenges. From 2014 to 2024, there has been significant growth in the number and quality of publications addressing SSI in the context of science education.

Table 3 shows a study covering 157 documents from 66 different sources, reflecting the breadth of interest and engagement of the scientific community in this topic. Although the annual growth rate shows a decrease of -1.17%, the relatively young average document age of 4.2 years makes it clear that the field continues to grow with significant new contributions.

All documents analyzed in this study were articles (157 articles) because journal articles, through a rigorous peer review process and standardized format, provide rich and structured data essential for bibliometric analysis, ensuring the dissemination of high-quality research that has significant impact and wide accessibility within the academic community. Each document has an average of 15.04 citations, indicating substantial academic impact within the scientific community. The number of references used reached 8833, indicating a broad and deep coverage of the literature. Keyword analysis showed that there were 174 Keywords Plus [ID] and 405 Author's Keywords [DE], indicating a rich diversity and research focus in this topic.

A total of 347 authors contributed to the research on SSI in science education, with 25 of them writing documents individually. Collaboration between authors was also evident with 29 documents written by a single author and an average of 2.65 co-authors per document. In addition, the international collaboration rate reached 20.38%, indicating that this research has a strong global dimension.

Table 3
Main Information

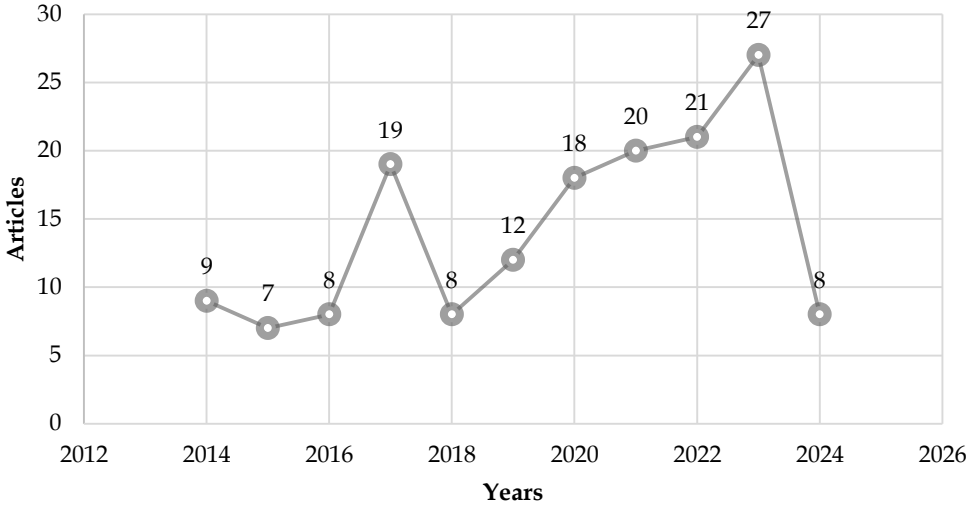
Description	*Results*
Main Information About Data	
Timespan	2014:2024
Sources (Journals, Books, etc)	66
Documents	157
Annual Growth Rate %	-1.17
Document Average Age	4.2
Average citations per doc	15.04
References	8833
Document Contents	
Keywords Plus	174
Author's Keywords	405
Authors	
Authors	347
Authors of single-authored docs	25
Authors Collaboration	
Single-authored docs	29
Co-Authors per Doc	2.65
International co-authorships %	20.38
Document Types	
Article	157

Note. Analysis by authors using Biblioshiny tool.

4.1.2. Publication trends of socioscientific issues in science education for sustainable development

Figure 2 illustrates the number of articles published from 2014 to 2024 in the research field of socioscientific issues in science education for sustainable development. During this period, it can be seen that the number of publications fluctuates every year. In 2014, the number of articles published was 9, but decreased to 7 in 2016. Scientific production increased sharply in 2019, with 19 articles published, compared to only 8 articles in 2018.

Figure 2
Annual Scientific Production

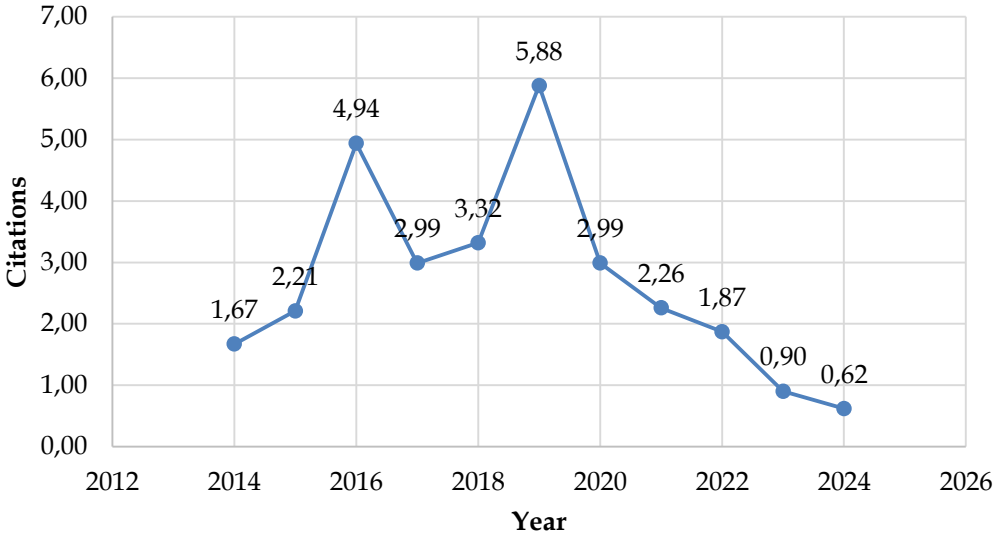


The growth trend continued gradually from 2019 to 2022, peaking in 2023 with 27 articles published, marking the highest-producing year of the decade. However, in 2024, there was a sharp decline with only 8 articles published. Nonetheless, in general, this graph shows an upward trend in the number of publications from 2014 to 2023, despite significant fluctuations each year.

Figure 3 shows the average number of citations per year for articles published in research on socioscientific issues in science education for sustainable development from 2014 to 2024. In 2014, the average citations per article was 1.67, and this figure increased to reach 2.21 in 2015. A significant spike occurred in 2016 with the average citation reaching 4.94 per article.

After 2016, the average citations per article fluctuated. In 2017, this figure decreased to 2.99 but increased again to 3.32 in 2018. 2019 recorded the highest peak in this period with an average of 5.88 citations per article. However, after this peak, there was a steady decline in average citations. In 2020, the average citations decreased to 2.99, and continued to decrease to 2.26 in 2021, 1.87 in 2022, 0.90 in 2023, until it reached its lowest point of 0.62 in 2024.

Figure 3
Avarage Citations Per Year



4.2. Contribution by Authors

Table 4 describes the production of top authors in socioscientific issues research in science education, revealing some important findings. Dana L. Zeidler from the University of South Florida emerges as the most productive and influential researcher in this area, with the highest number of publications and very significant total citations. Zeidler's dominance in these research contributions demonstrates his strong influence in the development and dissemination of knowledge regarding SSI in science education.

Table 4
Top-10 authors ranked by number of publications produced

Rank	*Authors*	*Institutions*	*Articles*	*TC*
1	Zeidler, Dana L.	University of South Florida, United States	8	536
2	Herman, Benjamin C.	Texas A&M University, United States	5	337
3	Namdar, Bahadir	Ege Üniversitesi, Turkey	5	58
4	Eilks, Ingo	University of Bremen, Germany	4	56
5	Karahan, Engin	Middle East Technical University (METU), Turkey	4	20
6	Sadler, Troy D.	The University of North Carolina, United States	4	162
7	Bögeholz, Susanne	Georg-August-Universität Göttingen, Germany	3	105
8	Christenson, Nina	Karlstads Universitet, Sweden	3	79
9	Dawson, Vaille	The University of Western Australia, Australia	3	76
10	Khishfe, Rola	American University of Beirut, Lebanon	3	42

Note. TC: Total citation.

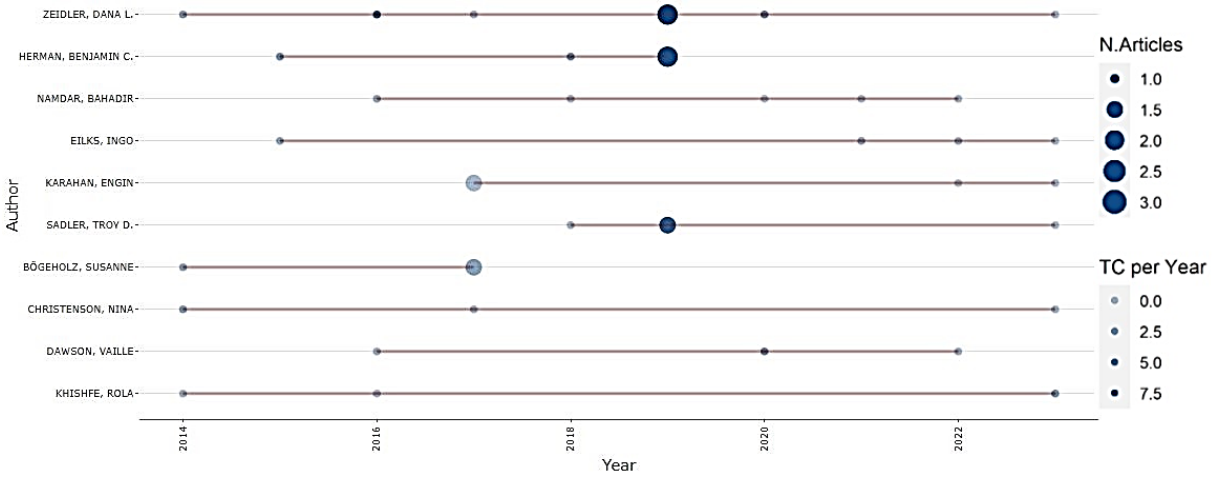
In addition, it is noticeable that the study is led by researchers from the United States, such as Zeidler and Benjamin C. Herman from Texas A&M University, which shows the strength of SSI research in this region. However, important contributions also came from researchers in Europe and Australia, such as Ingo Eilks from the University of Bremen and Vaille Dawson from The University of Western Australia, indicating a broad international collaboration and geographical diversification in this research.

Research on SSI in science education is not limited to one particular region. Researchers from different countries, such as Bahadir Namdar from Ege Üniversitesi in Türkiye and Rola Khishfe from the American University of Beirut in Lebanon, also contributed, showing that the issue is globally recognized and relevant in a variety of educational contexts. This indicates that attention to SSI in science education is a phenomenon that transcends geographical and cultural boundaries.

Although some researchers had fewer publications, the number of citations they received was high, indicating that the quality of their research is recognized and used as a reference by other researchers in this field. This signifies that their research has a significant impact and is considered important in the scientific community.

Research production by top authors shows a steady and sometimes increasing trend over time, reflecting consistent growth in research interest and investment in SSI for science education. This trend is relevant to the sustainable development goals, indicating that attention to socioscientific issues in science education continues to increase and is becoming increasingly important in the global effort to achieve these goals. Figure 4 illustrates the number of articles published each year by some of the most prominent authors in this field. Based on the graph, it can be seen that some authors show an increasing trend of article production over time.

Figure 4
Production of top-authors over time (Source: Authors' own elaboration, using bibliometrix)



Zeidler, Dana L. shows a consistent upward trend, signaling his commitment to producing quality scientific work. On the other hand, several other authors show flat or even declining production trends. This can be interpreted in various ways, such as a shift in research focus, a change in priorities, or even a decrease in productivity. The continued contribution of authors both in number and impact of publications, demonstrates the importance of this topic in the science education literature. This trend also suggests continued growth and innovation in the field, with an influx of new researchers and the development of new ideas relevant to contemporary socioscientific challenges.

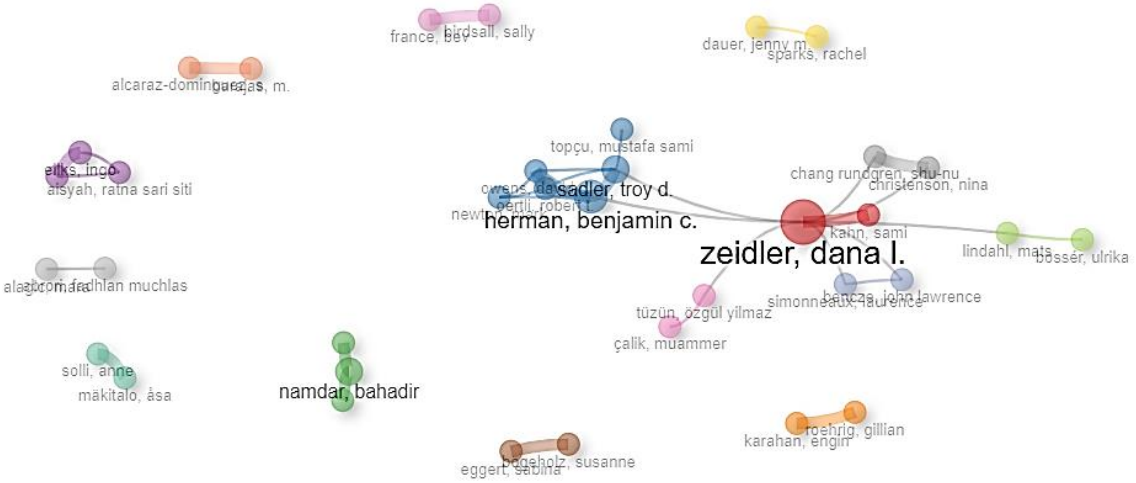
The author collaborative network in Figure 5 shows the relationships and collaborations between different researchers in the scientific community. The figure shows several interconnected groups of authors, with some authors standing out as centers of collaboration, as well as smaller groups showing more specialized collaborative relationships. Understanding these collaborative networks helps in recognizing influential research groups and potential interdisciplinary opportunities. Identifying these central figures can also assist new researchers in finding potential mentors or collaborators.

Author Dana L. Zeidler appears to be a central figure in this network, which suggests that Zeidler has many collaborations with other researchers. This central position suggests that Zeidler has great influence in his research community. Close collaborations with other authors such as Troy D. Sadler and Benjamin C. Herman further emphasizes Zeidler's important position in this network. Besides Zeidler, Troy D. Sadler and Benjamin C. Herman also show high levels of connectivity, suggesting that they have strong collaborative relationships with other researchers.

Figure 5 also shows some smaller groups of authors, indicating more specialized collaboration between some researchers. For example, Mustafa Sami Topcu and David Owens form a small group that shows a close collaborative relationship. Similarly, Ratna Sari Siti Aisyah and Ingo Eliks show a similar pattern of collaboration. Authors M. Alcaraz-Dominguez, Sebinia Eggert, and Gillian Roehrig are at the periphery of the network, suggesting that they have fewer collaborations in this dataset. However, this peripheral position does not necessarily reflect their overall influence in the academic community, but rather indicates more specialized or independent research activities.

The different colors represent different research themes, institutions, or regions, showing how collaborative efforts are clustered. The length and thickness of the lines between nodes represent the strength and frequency of collaboration, with thicker lines indicating stronger or more frequent collaboration.

Figure 5
Collaborative network between authors (Source: Authors' own elaboration, using bibliometrix)



4.3. Contribution by Journals

Based on bibliometric analysis of the top ten sources that most frequently publish articles related to socioscientific issues in science education, it appears that academic contributions in this field are heavily dominated by journals with high reputations. Journals such as Journal of Research in Science Teaching, Science and Education, International Journal of Science Education, and Research in Science Education show significant impact with a high number of publications and substantial total citations. The Scopus Q1 and WoS core collection [SSCI] indexes of these journals confirm the quality and relevance of the research published.

Table 5
Top-10 most frequently published sources ranked by number of publications

Rank	*Source*	*Publisher*	*NP*	*TC*	*Scopus Q**	*WoS core collection***	*SJR 2023*	*CiteScore 2023*
1	Journal of Research in Science Teaching	John Wiley & Sons	12	332	Q1	SSCI	1.906	8.8
2	Science and Education	Springer Nature	12	183	Q1	ESCI	1.121	5.9
3	International Journal of Science Education	Taylor & Francis	11	278	Q1	SSCI	0.965	4.6
4	Research in Science Education	Springer Nature	11	281	Q1	SSCI	1.045	6.4
5	Cultural Studies of Science Education	Springer Nature	9	306	Q1	SSCI/AHCI	0.725	3.1
6	International Journal of Science And Mathematics Education	Springer Nature	7	156	Q1	SSCI	1.038	5.1
7	Disciplinary and Interdisciplinary Science Education Research	Springer Open	6	135	-	ESCI	-	-
8	Education Sciences	MDPI	5	44	Q2	ESCI	0.669	4.8
9	Journal of Science Teacher Education	Taylor & Francis	5	42	Q1	ESCI	0.946	4.9
10	Science Education	Wiley-Blackwell	5	128	Q1	SSCI	1.543	6.6

In particular, Table 5 explains that the Journal of Research in Science Teaching stands out with the highest SJR and CiteScore, reflecting great influence in the science education research community. In addition, journals such as Cultural Studies of Science Education and International Journal of Science And Mathematics Education also make meaningful contributions with a focus on interdisciplinary studies and mathematics education, enriching the academic discourse around socioscientific issues. Although some journals such as Disciplinary and Interdisciplinary Science Education Research and Education Sciences have lower citation data and journal metrics, their presence in the ESCI index shows that they still make important contributions to developing understanding and research in this field.

4.4. Contribution by Countries

Based on the data presented in Table 6 there are some interesting patterns and trends in countries' contributions to research on socioscientific issues in continuing science education. This analysis reveals not only which countries are most productive in terms of number of publications but also how each publication is assessed based on its influence and impact within the academic community.

The United States emerged as the dominant leader in SSI research in science education. With 56 publications, the US has the highest number of publications among all the countries studied. This suggests that the academic community in the US is very active in learning and disseminating knowledge on socioscientific issues. However, what is more impressive is that the total citations reached 1153, which resulted in a citation per publication ratio of 20.6. This means that each publication from the US not only contributes quantitatively but also has great influence, reflecting the high quality of research and strong relevance in the global literature.

Looking at the average citations per article, New Zealand and Australia performed exceptionally well. Although New Zealand only has six publications, each article is cited 77 times on average, the highest number in this analysis. This shows that research from New Zealand has a huge impact and is widely appreciated in the scientific community. Australia also stood out with an average of 28.7 citations per article, showing that publications from this country are highly influential despite its relatively small total number of publications.

European countries such as Germany and Sweden also show significant contributions. With 14 publications each, these two countries have a high citation per publication ratio of 19 for Germany and 17.86 for Sweden. This places them as important contributors who are not only quantitatively active but also have a significant impact in the literature. Germany, in particular, has an average of 18.2 citations per article, which confirms that research from this country is highly valued and referred to by other researchers.

Table 6
Top-10 most productive countries ranked on number of publications

Rank	*Country*	*TP*	*TC*	*TC/TP*	*Average Article Citations*
1	USA	56	1153	20.58	20.6
2	Turkey	31	337	10.87	12.2
3	Germany	14	266	19	18.2
4	Sweden	14	250	17.85	14.8
5	Canada	9	163	18.11	25.2
6	Australia	6	97	16.16	28.7
7	France	5	79	15.8	20
8	New Zealand	6	77	12.83	77
9	Spain	4	40	10	17
10	Indonesia	5	39	7.8	9.8

Note. TP: Total paper; TC: Total citation.

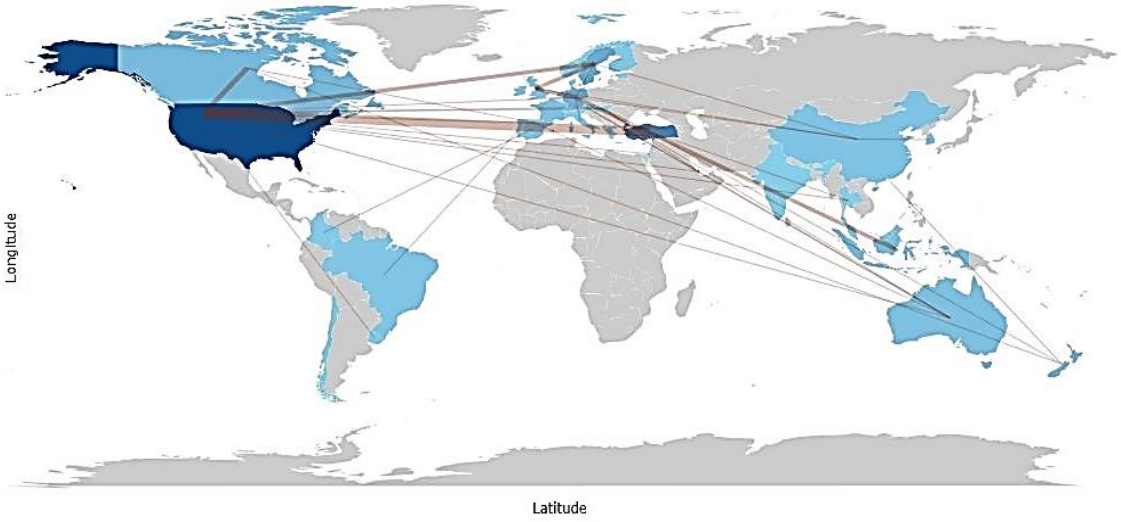
Turkey and Indonesia also contribute to SSI research, with Turkey taking second place in the number of publications (31 publications) and total citations (337). However, the ratio of citations per publication and average citations per article for Turkey show that although it is quantitatively active, there is an opportunity to increase the impact per publication. Indonesia, with five publications, shows a lower ratio of citations per publication (7.8) and average citations per article (9.8), indicating that there is room for further development in terms of research quality and impact.

The map of world collaboration between authors shown in Figure 6 shows the dynamics of research interactions in the field of science education, especially those related to socioscientific issues. This collaboration between authors from various countries reflects the integration and dissemination of knowledge and efforts to achieve sustainable development goals through science education.

The United States is a major center of collaboration with strong links to countries in Europe, Asia, and Australia. This dominance is evident from the darker color on the map, indicating a higher number of collaborations. Collaborations between the United States and European countries such as Germany and Sweden may reflect joint efforts in addressing global socioscientific issues such as climate change, sustainability education, and others.

Figure 6

World map of collaboration of authors between countries (Source: Authors' own elaboration, using Bibliometrix)



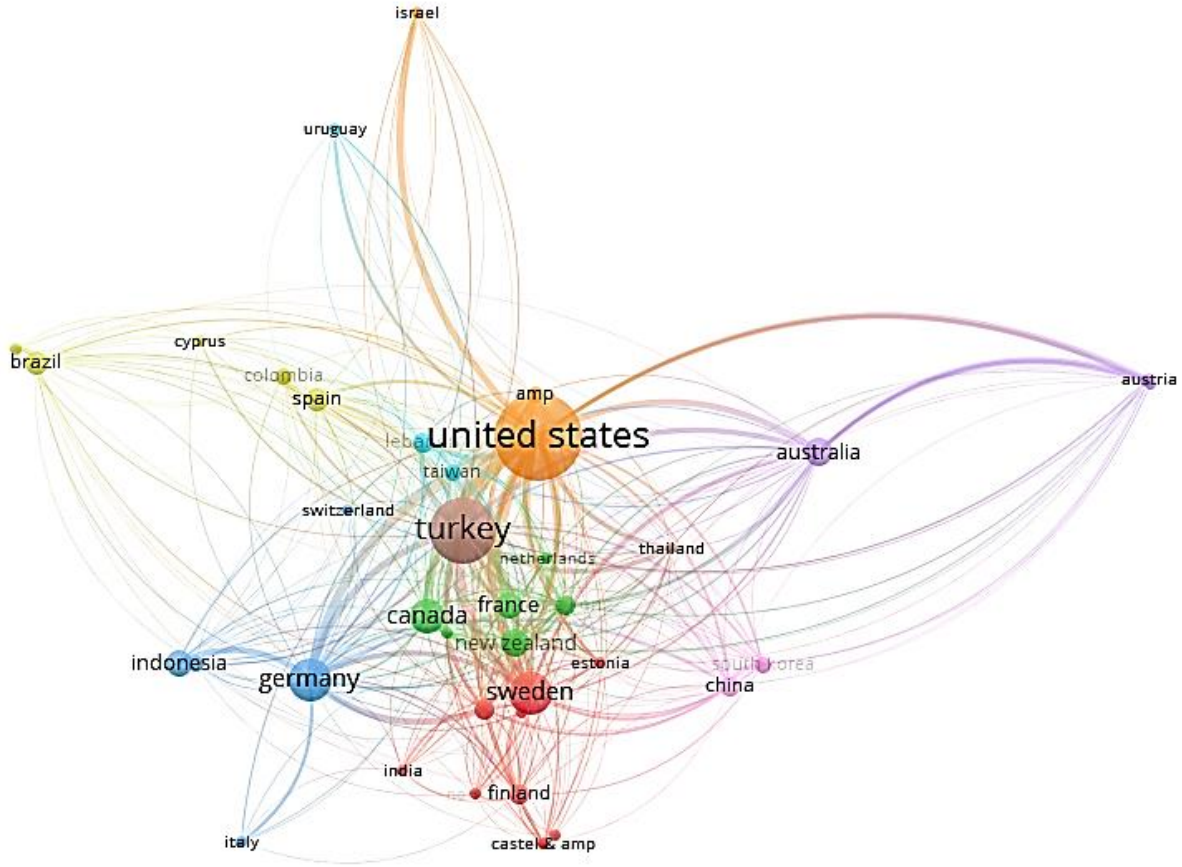
In addition, the involvement of countries such as Turkey, Lebanon, and several Asian countries shows that research related to socioscientific issues is not only a concern of developed countries, but also developing countries. This signifies global awareness and joint efforts in solving global challenges through inclusive and collaborative science education.

This pattern of collaboration also reflects a shift and broadening of research focus from merely local issues to global problems, demonstrating that knowledge and solutions are not limited by geographical boundaries. These collaborations strengthen the exchange of ideas and best practices, accelerate innovation, and increase the impact of research in solving complex global issues.

The visualization of bibliometric coupling in Figure 7 between countries in research on socioscientific issues provides an in-depth view of the dynamics of international collaboration and global knowledge flows in this field. Bibliometric coupling measures the relationship between scientific documents based on the references they share. When applied at the country scale, this method helps us understand how countries are interlinked in the production of scientific knowledge.

The United States plays a central role in this network, followed by European countries, Australia and Canada as major contributors. The involvement of developing countries demonstrates the increasing inclusiveness of this research. This network of cross-continental collaborations is crucial for knowledge exchange and progress in understanding and addressing socioscientific issues, ultimately supporting sustainable science education worldwide.

Figure 7
Bibliographic Coupling between Country (Source: Authors' own elaboration, using Vos Viewer)



4.5. Institutional Collaborative Networks

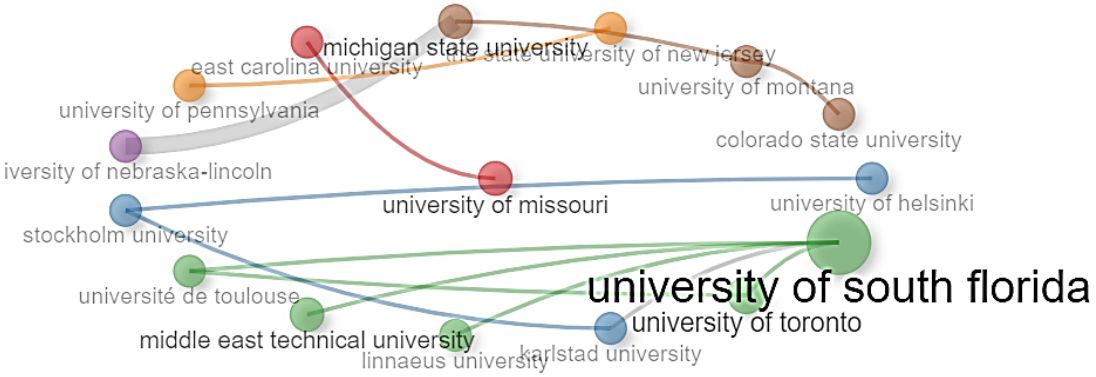
Figure 8 shows the collaborative networks between different academic institutions, illustrating the cooperative relationships and research collaborations between them. This figure is the author's elaboration using the bibliometrix tool to visualize this pattern of collaboration. These collaborative networks between institutions demonstrate the dynamics of cooperative relationships within the global academic community, which are essential for scientific innovation and development. By understanding these patterns, institutions can better coordinate their research efforts and encourage more productive collaborations in the future.

The University of South Florida appears to be the most prominent institution and has very high connectivity. The larger node size and central position indicate that the University of South Florida has many collaborations with other institutions. This indicates that the institution plays a key role in the global research network and is a major hub that coordinates or facilitates many research projects.

Other institutions that also stand out in this network are the University of Missouri and Michigan State University. These two institutions have some significant collaborative relationships, as shown by the thickness of the lines connecting them to other institutions. The strong links between the University of Missouri and the University of Helsinki, as well as the

visible links between Michigan State University and other institutions such as East Carolina University and the University of Montana, indicate active and ongoing research collaborations.

Figure 8
Collaboration Network between institutions (Source: Authors' own elaboration, using bibliometrix)



The network also shows some smaller but focused collaborative groups. For example, Middle East Technical University has close links with several European universities such as Université de Toulouse and Linnaeus University. These relationships indicate specific research projects or shared research themes being undertaken between these institutions.

Different colors in the network indicate thematic or geographical groups of collaborations. For example, the green line connecting the University of South Florida with other institutions such as the Middle East Technical University and the University of Toronto indicates a strong network of collaboration between them. Similarly, the red line connecting Michigan State University with other institutions indicates a collaborative group based in a particular region or area of research.

Institutions such as the University of Pennsylvania, University of Nebraska-Lincoln, and Stockholm University are in a more peripheral position, indicating that they have fewer collaborations in the context of this dataset. However, this peripheral position does not necessarily reflect their overall influence or contribution in the global academic community, but rather indicates a narrower specialization or research focus.

4.6. Analysis of Keywords and Main Topics that Appear in the Literature

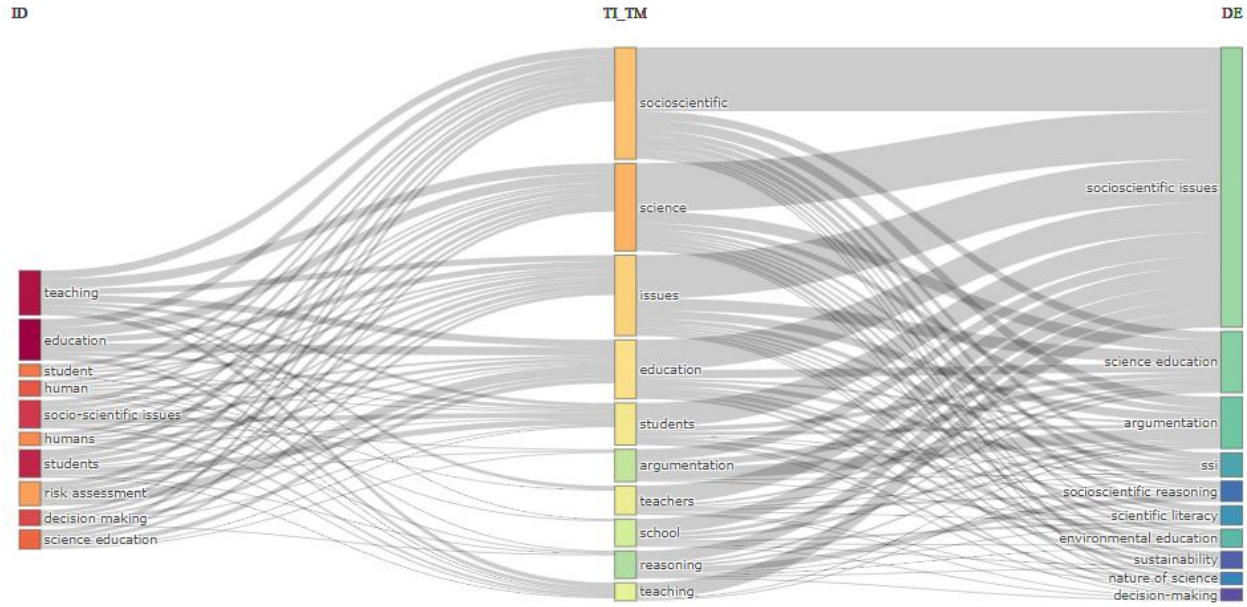
The Three-Field Plot visualization shown in Figure 9 provides deep insight into the relationship between document identification, primary keywords in the title and abstract [TI_TM], and research field or dominant keyword. This diagram helps in understanding how different research topics are connected to each other in academic literature. The Three-Field Plot is particularly useful for identifying global research trends, showing how different research topics are interrelated, and helping to find gaps in research that could be opportunities for further study. For example, research linking "students" and "argumentation" with "science education" shows academic attention to ways of improving student argumentation in science education.

The leftmost column of the diagram, which lists IDs, displays important words or phrases that appear frequently in the research documents. Words such as "teaching", "education", "student", "human" and "science education" appear frequently and are an important part of the literature. The frequency with which these words appear indicates the focus of research on these themes, reflecting significant academic attention to these topics. The middle column, which lists TI_TM, highlights the main topics found in the titles and abstracts of the research documents. Topics such as "sociocientific", "science", "issues", "education", "students", and "argumentation" indicate the main concentration areas of the analyzed research. The length of the box in this column illustrates how dominant these topics are in the literature, giving an indication of emerging research trends. The rightmost column, which lists DEs, shows the dominant research areas or keywords associated with the documents and main topics. Keywords such as "socio-scientific issues", "science

education", "argumentation", and "socio-scientific reasoning" reflect the research areas that appear most frequently in the analyzed literature. The length of the boxes in this column indicates the prevalence of each topic in the literature, providing insight into the popularity and relevance of these topics in current research.

Figure 9

Three-Field Plot between document identification, keyword or main topic in the title and abstract, and research field or dominant keyword (Source: Authors' own elaboration, using bibliometrix)



The lines connecting the boxes between the columns show the relationship between the key words in the documents, the main topics in the titles and abstracts, and the dominant research areas. For example, the line connecting "teaching" in the ID column to "sociocientific" in the TI_TM column shows that "teaching" is part of the main topic "sociocientific". Furthermore, the line connecting "sociocientific" to "sociocientific issues" in column DE shows that this topic is often associated with research on socioscientific issues.

Motor Themes (Top-Right Quadrant) describes the key themes of human, student and humans stand out as very important and well-developed themes in this research. These themes reflect a strong focus on the human and student aspects of science education and their role in addressing socioscientific issues. Strong theoretical development in these themes indicates significant and sustained research interest in this topic. Meanwhile, Basic Themes (Bottom-Right Quadrant) features themes such as education, students, and teaching. These themes form the main foundation of the SSI research area in science education, although they are less developed than the motor themes. This indicates ongoing foundational research in educational methodologies and student engagement in SSI discussions.

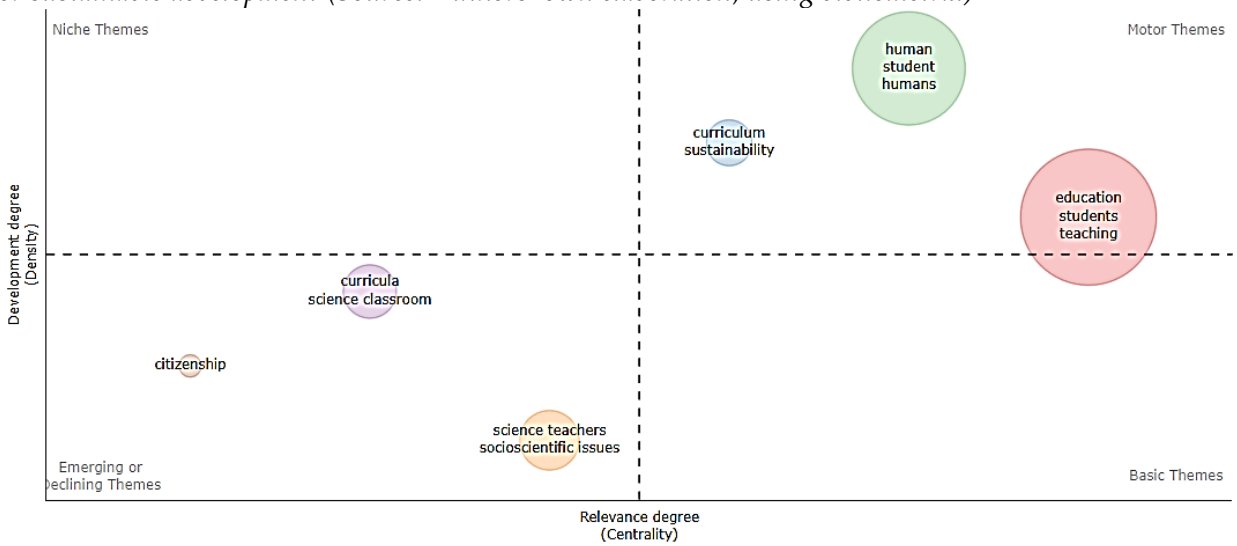
In the niche themes quadrant, we find themes such as curriculum and sustainability. These themes are well developed but not so central to the wider field. They represent emerging research areas or highly specialized topics, such as curriculum design for sustainability in science education. The emerging or declining themes quadrant shows themes such as citizenship that currently have low relevance and density. This could indicate an emerging research interest that has not yet become significant or an old topic that is losing its relevance in the current research context.

Additional themes such as science classroom and curricula fall between the basic and niche themes, showing moderate development and relevance. They represent research that focuses on the practical implementation of SSI in science classrooms and curriculum design. In addition, themes such as science teachers and socioscientific issues are in the emerging themes category, indicating a growing but less central interest in the role of science teachers and the specific

socioscientific issues addressed in education. Overall the thematic map in Figure 10 provides a rich visual representation of the SSI research landscape in science education for sustainable development. The map helps in identifying established themes, areas with growth potential, as well as themes that require further attention in this research. This is particularly useful for academics and researchers to understand existing trends and determine future research directions.

Figure 10

The thematic map of different themes in research publications on socioscientific issues in science education for sustainable development (Source: Authors' own elaboration, using bibliometrix)



The word cloud visualization in Figure 11 provides an overview of the focus and direction of research in socioscientific issues in science education. The significant emphasis on teaching, education, student engagement and decision-making suggests that this research seeks to integrate scientific understanding with practical applications in educational and teaching contexts. Topics such as climate change, sustainability and risk assessment also highlight the importance of science education in preparing students for global challenges. The word cloud image shows the most frequently used keywords in research on socioscientific issues in science education. The dominant keywords are teaching, education, students, and socio-scientific issues. This suggests that research in this area focuses heavily on the teaching process, education in general, and student engagement. Words such as decision making, science education, human, and curriculum also appeared frequently, indicating that this research emphasizes decision making, science education, human aspects, and curriculum as important elements in teaching SSI.

Other keywords that appear include climate change, sustainability and risk assessment, indicating that these topics are highly relevant in the context of SSI. These topics are often the focus of discussions on how science education can help students understand and address complex environmental and social issues critical to sustainable development.

The clustering and evolution of research themes in SSI (Socioscientific Issues) within science education reveal how the focus of research has shifted from the introduction of basic concepts to practical applications and direct impact. Themes such as science education, socioscientific issues, decision-making, climate change, and sustainability continue to be central, reflecting the importance of integrating SSI into education to prepare young generations to face global challenges.

In Table 7 shows several main groups emerge as research focuses. Themes like science education, socioscientific issues, and decision-making appear as central clusters, indicating high relevance and the broad scope of research related to how science education is used to address

Figure 11
Words cloud (base on keyword) in the field of socioscientific issues in science education (Source: Authors' own elaboration, using bibliometrix

significant social and scientific issues. These themes encompass various sub-themes related to enhancing scientific literacy, critical thinking, and student engagement in ethical decision-making regarding scientific issues.

There is also a cluster focused on the environment and sustainability, with themes such as climate change and sustainability. This cluster reflects global concern about environmental challenges and the importance of integrating these topics into science education to raise awareness and action among students. These themes demonstrate how science education can play a role in preparing students to face and solve future environmental challenges.

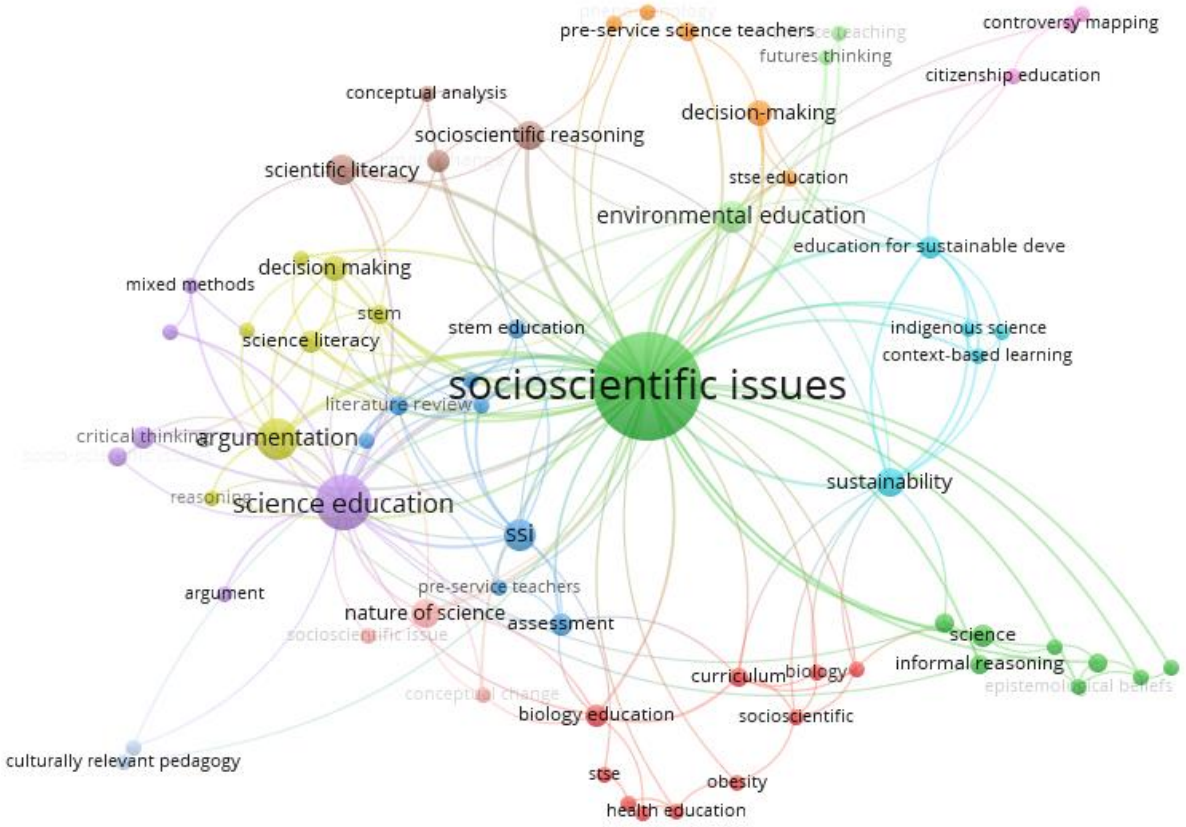
Table 7
The clustering of research themes

Cluster	*Items*
Cluster 1 (10 items)	Biology, Biology Education, Curriculum, Health Education, Inquiry-Based Learning, Obesity, Secondary Education, Socio-Scientific Issue, Socioscientific, STSE
Cluster 2 (9 items)	Attitudes, Epistemological Beliefs, Equity, Informal Reasoning, Preservice Science Teach, Science, Socioscientific Issues, Socioscientific Issues-Ba, Values
Cluster 3 (8 items)	Assessment, Educational Innovation, Formal Education, Literature Review, Pre-Service Teachers, SSI, STEM Education, Teacher Education
Cluster 4 (7 items)	Argumentation, Civic Engagement, Climate Change Education, Decision Making, Reasoning, Science Literacy, STEM
Cluster 5 (6 items)	Argument, Critical Thinking, Mixed Methods, Multiple Representations, Science Education, Socio-Scientific Issues
Cluster 6 (5 items)	Context-Based Learning, Education for Sustainable, Indigenous Science, Sustainability, Systems Thinking
Cluster 7 (5 items)	Decision-Making, Informal Science Educat, Phenomenology, Pre-Service Science Teac, STSE Education
Cluster 8 (4 items)	Climate Change, Conceptual Analysis, Scientific Literacy, Socioscientific Reasoning
Cluster 9 (3 items)	Citizenship Education, Controversy Mapping, Socioscientific Issues (SSI)
Cluster 10 (3 items)	Conceptual Change, Nature of Science, Socioscientific Issue
Cluster 11 (3 items)	Environmental Education, Futures Thinking, Science Teaching
Cluster 12 (2 items)	Culturally Relevant Pedagogy, Science and Society

Figure 12 presents a visualization of the network of concepts related to "socioscientific issues" (SSI) within the context of science education. In this diagram, "socioscientific issues" serves as the central node connecting various concepts, demonstrating how SSI interacts with multiple fields in science education. Concepts such as "science education," "environmental education," "scientific literacy," and "decision-making" are closely linked to SSI, highlighting the importance of this approach in developing critical thinking and decision-making skills among students. Additionally, concepts like "argumentation," "nature of science," "sustainability," and "culturally relevant pedagogy" emerge as significant elements associated with SSI teaching, indicating the various methods and perspectives used in education to address these issues. The broad scope and relevance of SSI in various aspects of science education, as well as the potential for interdisciplinary collaboration to advance the understanding and application of SSI in the context of sustainable learning, are evident.

Figure 12

Clustering research themes in socioscientific issues in science education (Source: Authors' own elaboration, using Vos Viewer)



A key opportunity lies in further exploration of how SSI can be used to develop students' scientific literacy and critical thinking skills, particularly in the context of ethical decision-making and solving complex problems. This research can explore various teaching approaches that integrate SSI, such as environmental education and scientific argumentation, to assess their effectiveness in enhancing students' understanding of science and its societal implications. Moreover, research opportunities are also available in developing more inclusive and culturally relevant teaching strategies, considering how different social and cultural contexts affect students' reception and understanding of SSI. With the increasing focus on sustainability and the role of science education in achieving it, there is an urgent need for research that examines how concepts such as sustainability and scientific literacy can be better integrated into the curriculum through

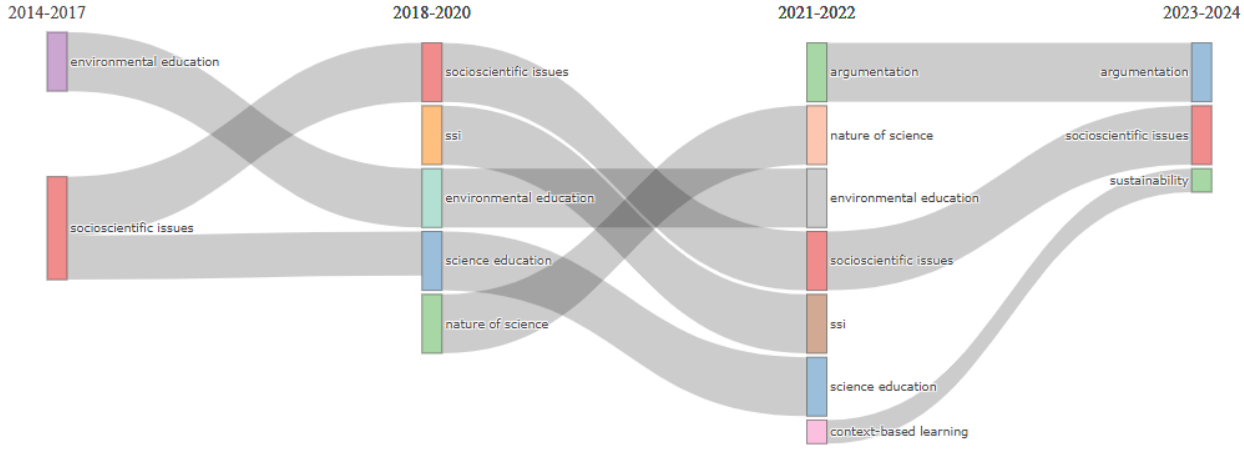
the lens of SSI, as well as how teachers can be prepared and supported to effectively teach these complex topics.

4.7. Dominant Research Themes and How these Evolved over Time

Figure 13 illustrates the evolution of research themes in socioscientific issues and science education from 2014 to 2024. During the period from 2014 to 2017, research primarily focused on environmental education and socioscientific issues, reflecting an initial concern with how environmental-related issues could be incorporated into education to enhance students' awareness and understanding of the environmental challenges facing the world.

Figure 13

Thematic Evolution of Research on Socioscientific Issues (SSI) in Science Education



In the following period, between 2018 and 2020, there was a diversification of research themes. While socioscientific issues remained a primary focus, new attention emerged on science education, the nature of science, and environmental education. These themes reflect a more holistic approach in research, with an emphasis on teaching that not only touches on environmental aspects but also delves into the scientific concepts themselves and how science is taught to students. Entering the period from 2021 to 2024, there was a significant shift toward the themes of argumentation and sustainability. Research began to focus on how argumentation skills can be developed within the context of SSI, which is crucial for strengthening students' critical thinking abilities. The theme of sustainability became increasingly prominent, indicating a direction in science education that is more integrated with global sustainability goals, showing that science education is now increasingly geared toward preparing students to face the complex and ever-evolving challenges of the real world.

5. Discussion

Overall the period from 2014 to 2024 reflects strong growth in research on socioscientific issues and sustainable science education. The decline in 2024 signals the importance of paying attention to the dynamics and external factors that may influence long-term trends in scientific publications. Although there were some years with significant increases in average citations, the general trend shows a decrease in the number of citations per article since 2019. This decline is attributed to various factors, including shifts in research focus, variations in the quality and impact of articles, or citation dynamics within the related academic community. This highlights the importance of critical evaluation of citation trends and research contributions in the field of SSI within science education for sustainable development.

Global events such as pandemics, political changes (Fages & Albe, 2015; Hodson, 2020), economic crises can have a major impact on research capacity (Hoeg et al., 2015). The COVID-19 pandemic disrupted many aspects of academic life in 2020 and 2021 (Chadwick & McLoughlin,

2022; Forsythe & Chan, 2021) and its impact could continue to be felt for years to come (Maia et al., 2021; Yapıcıoğlu, 2020). The decline in 2024 could be the after-effects of similar events, where resources are diverted or access to laboratory and research resources is limited.

The main objectives of integrating socioscientific issues in science education is to support sustainable development (UNESCO, 2017; Zeidler et al., 2019). By promoting a deep understanding of how science can be used to solve real-world problems, science education plays an important role in shaping individuals who are responsible and committed to sustainable development (Lenhart & Bouwma-Gearhart, 2022).

High-quality journals play a vital role in supporting and disseminating research on socioscientific issues in science education. Through publications that focus on the integration of critical issues into education, these journals help drive change in the way we view and teach science (Ban & Mahmud, 2023; Grosseck et al., 2019). The academic community's commitment to integrating critical issues such as sustainability, social justice, and climate change into science education is evident through the support provided by reputable journals. For example, journals such as "Journal of Research in Science Teaching", "Science Education", and "International Journal of Science Education" consistently publish articles that explore how socioscientific issues can be incorporated into science education curricula and practices

The significance of collaboration networks between academic institutions is very important in the context of the development of science and innovation (Fayzullina et al., 2023). These collaborative networks enable a broader exchange of ideas, resources and expertise among researchers from different backgrounds and natural science disciplines (Masalimova et al., 2024).

The future of science research increasingly relies on interdisciplinary approaches (Tosun, 2024). Collaborative networks allow researchers from different fields to work together, integrate knowledge, and create innovative solutions that would be impossible to achieve by one discipline alone. In addition, collaboration enables faster and wider access to new technologies and innovations. Institutions can share the latest technologies and best practices with each other, accelerating the translation of research findings into practical applications (Agbo et al., 2021; Arici et al., 2019).

The evolution of research topics and themes over time in the field of Socioscientific Issues shows significant dynamics and developments in related research over the past few years. At its core, "socioscientific issues" occupy a central position in this topic network, suggesting that these issues are becoming major themes that connect various aspects of science education. Related topics such as "science education," "decision-making," "critical thinking," and "sustainability" appear frequently in SSI-related research. This evolution indicates that SSI is not only considered important in isolation but also as an integral part of holistic and value-based science education (Cebesoy, 2021; Schenk et al., 2021).

Over time, shifts in research focus are observable. Topics such as "sustainability" and "climate change" have become increasingly dominant in recent years, represented by light yellow in the visualization, indicating more recent research (years 2022-2024). These results reflect the growing global awareness and urgency to address environmental issues through science education. In contrast, more established and general topics like "science education" and "critical thinking" remain important but tend to be more stable in publication numbers from year to year.

The connections between these topics are also interesting to observe. For instance, the topic of "decision-making" is often associated with "science education" and "critical thinking," indicating that decision-making in the context of SSI (Socio-Scientific Issues) is closely linked to educational approaches that focus on developing analytical and critical thinking skills. This suggests that research in SSI is not only focused on scientific content but also on the development of cognitive skills essential for understanding and solving the complex problems society faces today. Additionally, the topics of "science teachers" and "pre-service teachers" indicate a continuous effort to ensure that teachers are well-trained to teach SSI, so they can effectively guide students in understanding and addressing these issues. The transformation in methodological approaches is

also evident in topics such as "argumentation skills" and "critical thinking." These approaches emphasize the importance of argumentation and critical thinking in the process of SSI education, reflecting a paradigm shift in education that prioritizes the development of analytical skills over mere memorization of facts.

Overall, the literature analysis reveals several significant gaps that future research needs to address within the context of Socioscientific Issues (SSI) for sustainable science education. While existing studies have extensively explored how SSI can be integrated into the science education curriculum and how this integration can develop critical thinking and decision-making skills, certain areas remain underexplored (Chen & Xiao, 2021).

More in-depth empirical research is urgently needed to evaluate the effectiveness of various SSI teaching approaches (Bossér & Lindahl, 2019; Nielsen, 2020; Ottander & Simon, 2021). Much of the current research is conceptual or theoretical, which is important for framework development (Nielsen et al., 2020). However, without in-depth empirical research, it is difficult to identify best practices that can be applied across different educational contexts(Alcaraz-Dominguez & Barajas, 2021b; Baytelman et al., 2020). Longitudinal studies are also very limited, yet such research is crucial for understanding how SSI teaching affects the development of critical thinking skills, argumentation (Jafari & Meisert, 2021) , attitudes towards science, and students' decision-making abilities in the long term (Capkinoglu et al., 2020; Kinskey & Callahan, 2022; Leung, 2020).

Diversification of research contexts is also an urgent need (Chowdhury et al., 2020). Most SSI research is conducted in developed countries, particularly in the United States and Europe. There is a need to expand this research to developing countries and more diverse contexts to understand how different cultural, social, and economic factors influence the implementation and effectiveness of SSI teaching (Herman et al., 2022; Leung, 2022b).

The integration of technology in SSI teaching is another under-researched area (Albe & Pedretti, 2013; Chen & Xiao, 2021; Owens et al., 2019). Given the rapid technological advancements, there is a significant opportunity to explore how digital tools and online platforms can be used to make SSI learning more interactive and engaging for students (Calik & Karatas, 2019; Gandolfi, 2024). The use of technology such as computer simulations (Araiza-Alba et al., 2021; Mystakidis & Christopoulos, 2022; Namdar & Shen, 2018; Rojas-Sánchez et al., 2023), game-based learning (Mystakidis & Christopoulos, 2022; Stoeffler et al., 2020), and online learning platforms can enhance student engagement and the effectiveness of learning (Lawson & Lawson, 2020; Solli, 2021).

The development and validation of assessment tools are also crucial for measuring the critical thinking and decision-making skills developed through SSI teaching (Capkinoglu et al., 2020; Herman, 2018). These tools are needed to objectively evaluate the effectiveness of SSI education programs and provide useful feedback for program improvement (Christenson et al., 2017; Klosterman, 2010; Rahayu & Rosawati, 2023).

The evolution of research topics and themes over time shows that topics such as science education, decision-making, and sustainability are receiving increasing attention. These themes indicate that SSI research continues to evolve and adapt to emerging global issues, such as climate change and sustainability. Through this ongoing research, it is hoped that new and innovative ways of integrating SSI into science education can be found, ultimately preparing students to face the complex challenges of the modern world (Chen & Xiao, 2021).

6. Conclusion

This research provides an in-depth analysis of trends and frontiers in Socioscientific Issues research for sustainable science education. The main findings indicate that topics such as science education, scientific literacy, climate change, and sustainability have become key focuses in SSI research. Additionally, there has been a significant increase in international collaboration, particularly between the United States, Turkey, and European countries, which strengthens the global research network in this field. This research is crucial in the context of science education for

sustainable development as it identifies critical focus areas and demonstrates how international collaboration can accelerate progress in science education. By combining bibliometric approaches and systematic reviews, this study offers valuable insights for educators, researchers, and policymakers to develop more effective strategies for integrating SSI into the science curriculum.

This research has several limitations. First, the bibliometric analysis only includes publications in certain databases, such as Scopus and ERIC, which means some relevant research may be excluded, necessitating the inclusion of other indices like Web of Science. Second, the focus on publications in English may introduce linguistic bias and overlook important contributions from research in other languages. Third, while the analysis of collaboration networks provides insights into the relationships between researchers and countries, it does not offer in-depth details about the nature of the collaborations or the specific outcomes of these partnerships.

Acknowledgements: Sincere gratitude is extended to Lembaga Pengelola Dana Pendidikan (LPDP) for the scholarship support that made the continuation of this study possible. The financial support and guidance from LPDP have been a crucial foundation in achieving academic success.

Author contribution: All authors reviewed and approved the final manuscript and contributed equally to the discussion of the results and their implications for future research in socioscientific issues and sustainable science education.

Declaration of interest: The authors declared that there were no potential conflicts of interest.

Data availability: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethical statement: Because no human studies are included, this study does not require ethical approval.

Funding: This research was supported by Lembaga Pengelola Dana Pendidikan (LPDP) under the Indonesian Ministry of Finance with registration number 0001086/TRP/D/19/LPDP2023.

References

Abrori, F. M., Prodromou, T., Alagic, M., Livits, R., Kasti, H., Lavicza, Z., & Anđić, B. (2024). Integrating mathematics and science to explain socioscientific issues in educational comics for elementary school students. *Journal of Graphic Novels and Comics*, *15*(4), 508–524. https://doi.org/10.1080/21504857.2023.2292734

Agbo, F. J., Sanusi, I. T., Oyelere, S. S., & Suhonen, J. (2021). Application of virtual reality in computer science education: A systemic review based on bibliometric and content analysis methods. *Education Sciences*, *11*(3), 142. https://doi.org/10.3390/educsci11030142

Albe, V., & Pedretti, E. (2013). Introduction to the special issue on courting controversy: socioscientific issues and school science and technology. *Canadian Journal of Science, Mathematics and Technology Education*, *13*(4), 303–312. https://doi.org/10.1080/14926156.2013.847219

Alcaraz-Dominguez, S., & Barajas, M. (2021a). Conceiving socioscientific issues in Stem lessons from science education research and practice. *Education Sciences*, *11*(5), 238. https://doi.org/10.3390/educsci11050238

Alcaraz-Dominguez, S., & Barajas, M. (2021b). Conceptualization of socioscientific issues in educational practice from a review of research in science education. *International Journal of Information and Education Technology*, *11*(6), 297–302. https://doi.org/10.18178/ijiet.2021.11.6.1526

Araiza-Alba, P., Keane, T., Chen, W. S., & Kaufman, J. (2021). Immersive virtual reality as a tool to learn problem-solving skills. *Computers & Education*, *164*, 104121. https://doi.org/10.1016/j.compedu.2020.104121

Arici, F., Yildirim, P., Caliklar, Ş., & Yilmaz, R. M. (2019). Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis. *Computers & Education*, *142*, 103647. https://doi.org/10.1016/j.compedu.2019.103647

Bader, J. D., Ahearn, K. A., Allen, B. A., Anand, D. M., Coppens, A. D., & Aikens, M. L. (2023). The decision is in the details: Justifying decisions about socioscientific issues. *Journal of Research in Science Teaching*, *60*(10), 2147–2179. https://doi.org/10.1002/tea.21854

Ban, S., & Mahmud, S. N. D. (2023). Research and trends in socio-scientific issues education: a content analysis of journal publications from 2004 to 2022. *Sustainability*, *15*(15), 11841. https://doi.org/10.3390/su151511841

Ban, S., & Mahmud, S. N. D. (2024). A systematic review of the top-50 most-cited articles on socio-scientific issues in K-12 education. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(4), em2425. https://doi.org/10.29333/ejmste/14379

Bay, J. L., Vickers, M. H., Mora, H. A., Sloboda, D. M., & Morton, S. M. (2017). Adolescents as agents of healthful change through scientific literacy development: A school-university partnership program in New Zealand. *International Journal of STEM Education*, *4*(1), Article 15. https://doi.org/10.1186/s40594-017-0077-0

Baytelman, A., Iordanou, K., & Constantinou, C. P. (2020). Epistemic beliefs and prior knowledge as predictors of the construction of different types of arguments on socioscientific issues. *Journal of Research in Science Teaching*, *57*(8), 1199–1227. https://doi.org/10.1002/tea.21627

Bencze, L., Pouliot, C., Pedretti, E., Simonneaux, L., Simonneaux, J., & Zeidler, D. (2020). SAQ, SSI and STSE education: defending and extending "science-in-context." *Cultural Studies of Science Education*, *15*(3), 825–851. https://doi.org/10.1007/s11422-019-09962-7

Bossér, U. (2024). Transformation of School Science Practices to Promote Functional Scientific Literacy. *Research in Science Education*, *54*(2), 265–281. https://doi.org/10.1007/s11165-023-10138-1

Bossér, U., & Lindahl, M. (2019). Students' Positioning in the Classroom: a Study of Teacher-Student Interactions in a Socioscientific Issue Context. *Research in Science Education*, *49*(2), 371–390. https://doi.org/10.1007/s11165-017-9627-1

Büssing, A. G., Dupont, J., & Menzel, S. (2020). Topic Specificity and Antecedents for Preservice Biology Teachers' Anticipated Enjoyment for Teaching About Socioscientific Issues: Investigating Universal Values and Psychological Distance. *Frontiers in Psychology*, *11*, 1536. https://doi.org/10.3389/fpsyg.2020.01536

Cabello, V. M., Zúñiga, C. G., Valbuena, C. A., Manrique, F., Albarrán, M. J., & Moncada-Arce, A. (2024). "We are not being taught sustainable citizenship!": Podcasts for critical science literacy in teacher education. *LUMAT*, *12*(2), 18–49. https://doi.org/10.31129/LUMAT.12.2.2135

Calik, M., & Karatas, F. (2019). Does a "science, technology and social change" course improve scientific habits of mind and attitudes towards socioscientific issues? *Australian Journal of Teacher Education*, *44*(6), 35–52. https://doi.org/10.14221/ajte.2018v44n6.3

Capkinoglu, E., Yilmaz, S., & Leblebicioglu, G. (2020). Quality of argumentation by seventh-graders in local socioscientific issues. *Journal of Research in Science Teaching*, *57*(6), 827–855. https://doi.org/10.1002/tea.21609

Cebesoy, U. B. (2021). Pre-service science teachers' informal reasoning patterns and risk perceptions in ssi: case of gene therapy. *European Journal of Science and Mathematics Education*, *9*(4), 211–229. https://doi.org/10.30935/scimath/11237

Chadwick, R., & McLoughlin, E. (2022). Irish secondary school science teachers' perspectives on addressing the COVID-19 crisis as socioscientific issues. *Disciplinary and Interdisciplinary Science Education Research*, *4*(1), Article 16. https://doi.org/10.1186/s43031-022-00056-z

Chen, L., & Xiao, S. (2021). Perceptions, challenges and coping strategies of science teachers in teaching socioscientific issues: A systematic review. *Educational Research Review*, *32*, 100377. https://doi.org/10.1016/j.edurev.2020.100377

Chowdhury, T., Holbrook, J., & Rannikmäe, M. (2020). Socioscientific issues within science education and their role in promoting the desired citizenry. *Science Education International*, *31*(2), 203–208. https://doi.org/10.33828/sei.v31.i2.10

Christenson, N., Gericke, N., & Rundgren, S.-N. C. (2017). Science and language teachers' assessment of upper secondary students' socioscientific argumentation. *International Journal of Science and Mathematics Education*, *15*(8), 1403–1422. https://doi.org/10.1007/s10763-016-9746-6

Dawson, V., & Carson, K. (2020). Introducing argumentation about climate change socioscientific issues in a disadvantaged school. *Research in Science Education*, *50*(3), 863–883.

https://doi.org/10.1007/s11165-018-9715-x
Dawson, V., & Venville, G. (2022). Testing a methodology for the development of socioscientific issues to enhance middle school students' argumentation and reasoning. *Research in Science & Technological Education*, *40*(4), 499–514. https://doi.org/10.1080/02635143.2020.1830267
de Freitas, A. C., do Nascimento, L. A., de Castro, R. G., Motokane, M. T., & Reis, P. (2023). Biodiversity and Citizenship in an Argumentative Socioscientific Process. *Sustainability*, *15*(4), 2987. https://doi.org/10.3390/su15042987
Eggert, S., Nitsch, A., Boone, W. J., Nückles, M., & Bögeholz, S. (2017). Supporting students' learning and socioscientific reasoning about climate change—the effect of computer-based concept mapping scaffolds. *Research in Science Education*, *47*(1), 137–159. https://doi.org/10.1007/s11165-015-9493-7
Fadzil, H. M. (2017). Exploring early childhood preservice teachers' problem-solving skills through socioscientific inquiry approach. *Asia-Pacific Forum on Science Learning and Teaching*, *18*(1), Article 9.
Fages, V., & Albe, V. (2015). Social issues in nanoscience and nanotechnology master's degrees: the socio-political stakes of curricular choices. *Cultural Studies of Science Education*, *10*(2), 419–435. https://doi.org/10.1007/s11422-014-9593-0
Fayzullina, A. R., Zakirova, C. S., Dobrokhotov, D. A., Erkiada, G., Muratova, O. A., & Grishnova, E. E. (2023). Bibliometric review of articles related to context-based learning in science education. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(9), em2330. https://doi.org/10.29333/EJMSTE/13534
Forsythe, M. E., & Chan, Y.-W. (2021). Justice-centered education amid the COVID-19 pandemic. *Journal of Environmental Education*, *52*(5), 347–357. https://doi.org/10.1080/00958964.2021.1981208
Gandolfi, H. E. (2024). (Re)considering nature of science education in the face of socio-scientific challenges and injustices. *Science & Education*. Advance Online Publication. https://doi.org/10.1007/s11191-024-00536-w
Garrecht, C., Czinczel, B., Kretschmann, M., & Reiss, M. J. (2023). Should we be doing it, should we not be doing it, who could be harmed?: addressing ethical issues in science education. *Science and Education*, *32*(6), 1761-1793. https://doi.org/10.1007/s11191-022-00342-2
Genel, A., & Topçu, M. S. (2016). Turkish preservice science teachers' socioscientific issues-based teaching practices in middle school science classrooms. *Research in Science & Technological Education*, *34*(1), 105–123. https://doi.org/10.1080/02635143.2015.1124847
Grace, M., Lee, Y. C., Asshoff, R., & Wallin, A. (2015). Student Decision-Making about a Globally Familiar Socioscientific Issue: The value of sharing and comparing views with international counterparts. *International Journal of Science Education*, *37*(11), 1855–1874. https://doi.org/10.1080/09500693.2015.1054000
Grosseck, G., Tîru, L. G., & Bran, R. A. (2019). Education for sustainable development: Evolution and perspectives: A bibliometric review of research, 1992-2018. *Sustainability*, *11*(21), 1992–2018. https://doi.org/10.3390/su11216136
Herman, B. C. (2018). Students' environmental NOS views, compassion, intent, and action: Impact of place-based socioscientific issues instruction. *Journal of Research in Science Teaching*, *55*(4), 600–638. https://doi.org/10.1002/tea.21433
Herman, B. C., Clough, M. P., & Rao, A. (2022). Socioscientific issues thinking and action in the midst of science-in-the-making. *Science & Education*, *31*(5), 1105–1139. https://doi.org/10.1007/s11191-021-00306-y
Herman, B. C., Owens, D. C., Oertli, R. T., Zangori, L. A., & Newton, M. H. (2019). Exploring the complexity of students' scientific explanations and associated nature of science views within a place-based socioscientific issue context. *Science & Education*, *28*(3–5), 329–366. https://doi.org/10.1007/s11191-019-00034-4
Hodson, D. (2020). Going beyond sts education: building a curriculum for sociopolitical activism. *Canadian Journal of Science, Mathematics and Technology Education*, *20*(4), 592–622. https://doi.org/10.1007/s42330-020-00114-6
Hoeg, D., Lemelin, N., & Bencze, J. L. (2015). Sociopolitical development of private school children mobilising for disadvantaged others. *Cultural Studies of Science Education*, *10*(4), 1155–1174. https://doi.org/10.1007/s11422-014-9611-2
Husamah, H., Suwono, H., Nur, H., & Dharmawan, A. (2022a). Action competencies for sustainability

and its implications to environmental education for prospective science teachers: A systematic literature review. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(8), 12235. https://doi.org/10.29333/ejmste/12235

Husamah, H., Suwono, H., Nur, H., & Dharmawan, A. (2022b). Sustainable development research in Eurasia Journal of Mathematics, Science and Technology Education: A systematic literature review. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(5), 11965. https://doi.org/10.29333/ejmste/11965

Husamah, H., Suwono, H., Nur, H., Dharmawan, A., & Chang, C.-Y. (2023). The existence of environmental education in the COVID-19 pandemic: A systematic literature review. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(11), 13668. https://doi.org/10.29333/ejmste/13668

Ibragimov, G. I., Murkshtis, M., Zaitseva, N. A., Kosheleva, Y. P., Sadykova, A. R., & Shindryaeva, N. N. (2023). Research trends on learning environment in science education. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(11), em2351. https://doi.org/10.29333/ejmste/13680

Itzek-Greulich, H., & Vollmer, C. (2017). Emotional and motivational outcomes of lab work in the secondary intermediate track: The contribution of a science center outreach lab. *Journal of Research in Science Teaching*, *54*(1), 3–28. https://doi.org/10.1002/tea.21334

Iversen, E., & Jónsdóttir, G. (2019). 'We did see the lapwing'–practising environmental citizenship in upper-secondary science education. *Environmental Education Research*, *25*(3), 411–421. https://doi.org/10.1080/13504622.2018.1455075

Jackson, W. M., Binding, M. K., Grindstaff, K., Hariani, M., & Koo, B. W. (2023). Addressing sustainability in the high school biology classroom through socioscientific Issues. *Sustainability*, *15*(7), 5766. https://doi.org/10.3390/su15075766

Jafari, M., & Meisert, A. (2021). Activating students' argumentative resources on socioscientific issues by indirectly instructed reasoning and negotiation processes. *Research in Science Education*, *51*(S2), 913–934. https://doi.org/10.1007/s11165-019-09869-x

Johnson, J. A., Batkie, R., Macalalag, A., Dunphy, J., & Titus, S. (2023). Socioscientific issues and STEM learning. *International Encyclopedia of Education, 2023,* 143–152. https://doi.org/10.1016/B978-0-12-818630-5.13051-9

Karahan, E. (2022). The lived experiences of pre-service science teachers designing and teaching socioscientific issues-based units. *Disciplinary and Interdisciplinary Science Education Research*, *4*(1), 24. https://doi.org/10.1186/s43031-022-00064-z

Karakaş, H. (2022). The Effect of Socioscientific Issues-Based Discussion Activities on the Attitudes of Primary School Teacher Candidates to the Life Science Teaching. *Journal of Turkish Science Education*, *19*(1), 17–36. https://doi.org/10.36681/tused.2022.107

Karakaya, E., & Irez, O. S. (2022). The relationship between understanding the nature of scientific knowledge and reasoning and decision making in socioscientific issues. *Hacettepe University Journal of Education*, *37*(4), 1329–1358. https://doi.org/10.16986/HUJE.2022.452

Khishfe, R. (2014). A reconstructed vision of environmental science literacy: the case of Qatar. *International Journal of Science Education*, *36*(18), 3067–3100. https://doi.org/10.1080/09500693.2014.951980

Kinskey, M., & Callahan, B. E. (2022). The influences of socioscientific issues on general science teaching self-efficacy. *Research in Science Education*, *52*(5), 1451–1465. https://doi.org/10.1007/s11165-021-09991-9

Kinskey, M., & Newton, M. (2024). Teacher candidates' views of future SSI instruction: a multiple case study. *Disciplinary and Interdisciplinary Science Education Research*, *6*(1), Article 8. https://doi.org/10.1186/s43031-024-00098-5

Klaver, L. T., Walma van der Molen, J. H., Sins, P. H. M., & Guérin, L. J. F. (2023). Students' engagement with Socioscientific issues: Use of sources of knowledge and attitudes. *Journal of Research in Science Teaching*, *60*(5), 1125–1161. https://doi.org/10.1002/tea.21828

Klopfer, L. E., & Aikenhead, G. S. (2022). Humanistic science education: The history of science and other relevant contexts. *Science Education*, *106*(3), 490–504. https://doi.org/10.1002/sce.21700

Klosterman, M. (2010). Multi-level assessment of scientific content knowledge gains associated with

socioscientific issues-based instruction. *International Journal of Science Education*, *32*(8), 1017–1043. https://doi.org/10.1080/09500690902894512

Kong, Z., Zhang, S., Zhu, F., & Zhang, J. (2022). The development and prospects of socioscientific issues teaching in the context of immersive media technology. *Frontiers in Psychology*, *13,* 877311. https://doi.org/10.3389/fpsyg.2022.877311

Lawson, H., & Lawson, M. (2020). Student engagement and disengagement as a collective action problem. *Education Sciences*, *10*(8), 212. https://doi.org/10.3390/educsci10080212

Le Thi Tuyet, T., Nguyen Thi, K., Tran Duc, H., Tran Thi Giao, X., Vo Thi, N., Huynh Kim Tuong, V., Do Thi Nhu, U., & Le Thi Mai, A. (2024). STEM education in primary schools of Southeast Asian countries: An analysis of scientific publications in the Scopus database from 2000 to 2022. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(4), em2433. https://doi.org/10.29333/ejmste/14432

Lee, H. (2022). Pedagogical and epistemological challenges of pre-service science teachers teaching socioscientific issues. *Asia-Pacific Science Education*, *8*(2), 301–330. https://doi.org/10.1163/23641177-bja10050

Leicht, A., Heiss, J., & Byun, W. J. (2018). *Issues and trends in education for sustainable development*. UNESCO. https://doi.org/10.54675/YELO2332

Lenhart, C., & Bouwma-Gearhart, J. (2022). Engaging students around the complex socioscientific issue of sustainability: affordances and tensions of faculty working across disciplines to develop transdisciplinary curricula. *CBE—Life Sciences Education*, *21*(2), ar21. https://doi.org/10.1187/cbe.21-03-0075

Lesnefsky, R. R., Kirk, E. A., Yeldell, J., Sadler, T. D., & Ke, L. (2023). Socioscientific modelling as an approach towards justice-centred science pedagogy. *London Review of Education*, *21*(1), 30. https://doi.org/10.14324/LRE.21.1.30

Lestari, N., & Suyanto, S. (2024). A systematic literature review about local wisdom and sustainability: Contribution and recommendation to science education. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(2), 1–19. https://doi.org/10.29333/ejmste/14152

Leung, J. S. C. (2020). Promoting students' use of epistemic understanding in the evaluation of socioscientific issues through a practice-based approach. *Instructional Science*, *48*(5), 591–622. https://doi.org/10.1007/s11251-020-09522-5

Leung, J. S. C. (2022a). A practice-based approach to learning nature of science through socioscientific issues. *Research in Science Education*, *52*(1), 259–285. https://doi.org/10.1007/s11165-020-09942-w

Leung, J. S. C. (2022b). Shifting the teaching beliefs of preservice science teachers about socioscientific issues in a teacher education course. *International Journal of Science and Mathematics Education*, *20*(4), 659–682. https://doi.org/10.1007/s10763-021-10177-y

Levy, B. L. M., Oliveira, A. W., & Harris, C. B. (2021). The potential of "civic science education": Theory, research, practice, and uncertainties. *Science Education*, *105*(6), 1053–1075. https://doi.org/10.1002/sce.21678

Lombard, F., Schneider, D. K., Merminod, M., & Weiss, L. (2020). Balancing emotion and reason to develop critical thinking about popularized neurosciences. *Science & Education*, *29*(5), 1139–1176. https://doi.org/10.1007/s11191-020-00154-2

Maia, P., Justi, R., & Santos, M. (2021). Aspects about science in the context of production and communication of knowledge of COVID-19. *Science and Education*, *30*(5), 1075–1098. https://doi.org/10.1007/s11191-021-00229-8

Masalimova, A. R., Kabardov, M. K., Kosheleva, Y. P., Omarova, L. B., Zamaraeva, E. I., Dobrokhotov, D. A., & Fattakhova, S. F. (2024). Research on mentoring in science education: A bibliometric analysis. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(1), em2391. https://doi.org/10.29333/ejmste/14122

Mystakidis, S., & Christopoulos, A. (2022). teacher perceptions on virtual reality escape rooms for stem education. *Information*, *13*(3), 136. https://doi.org/10.3390/info13030136

Namdar, B., & Namdar, A. O. (2022). Role reversal to facilitate social & moral compassion: a case for climate change as an ethics dilemma. *American Biology Teacher*, *84*(4), 242–245. https://doi.org/10.1525/abt.2022.84.4.242

Namdar, B., & Shen, J. (2018). Knowledge organization through multiple representations in a

computer-supported collaborative learning environment. *Interactive Learning Environments*, *26*(5), 638–653. https://doi.org/10.1080/10494820.2017.1376337

Navas Iannini, A. M. (2023). Socioscientific issues in science exhibitions: examining contributions of the informal science education sector. *Journal of Science Communication*, *22*(02), 202. https://doi.org/10.22323/2.22020202

Nida, S., Mustikasari, V. R., & Eilks, I. (2021). Indonesian Pre-Service Science Teachers' Views on Socio-Scientific Issues-Based Science Learning. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(1), 1–11. https://doi.org/10.29333/ejmste/9573

Nielsen, J. A. (2020). Teachers and socioscientific issues – an overview of recent empirical research. In M. Evagorou, J. A. Nielsen, & J. Dillon (Eds.), *Contemporary trends and issues in science education* (Vol. 52, pp. 13–20). Springer. https://doi.org/10.1007/978-3-030-40229-7_2

Nielsen, J. A., Evagorou, M., & Dillon, J. (2020). New perspectives for addressing socioscientific issues in teacher education. In M. Evagorou, J. A. Nielsen, & J. Dillon (Eds.), *Contemporary Trends and Issues in Science Education* (Vol. 52, pp. 193–199). Springer. https://doi.org/10.1007/978-3-030-40229-7_12

Ottander, K., & Simon, S. (2021). Learning democratic participation? Meaning-making in discussion of socioscientific issues in science education. *International Journal of Science Education*, *43*(12), 1895–1925. https://doi.org/10.1080/09500693.2021.1946200

Owens, D. C., Herman, B. C., Oertli, R. T., Lannin, A. A., & Sadler, T. D. (2019). Secondary Science and Mathematics Teachers' Environmental Issues Engagement through Socioscientific Reasoning. *EURASIA Journal of Mathematics, Science and Technology Education*, *15*(6), 103561. https://doi.org/10.29333/ejmste/103561

Ozcan-Ermis, G., & Hervé, N. (2023). Identifying pre- and in-service teachers' stances on teaching socioscientific issues: a systematic review of empirical studies. *Canadian Journal of Science, Mathematics and Technology Education*, *23*(4), 741–764. https://doi.org/10.1007/s42330-023-00306-w

Pham-Duc, B., Nguyen, H., Le Minh, C., Khanh, L. H., & Trung, T. (2020). A bibliometric and content analysis of articles in remote sensing from Vietnam indexed in Scopus for the 2000–2019 period. *Serials Review*, *46*(4), 275–285. https://doi.org/10.1080/00987913.2020.1854155

Powell, W. (2023). A socioscientific issues approach to ninth-graders' understanding of COVID-19 on health, wealth, and educational attainments. *PLOS ONE*, *18*(3), e0280509. https://doi.org/10.1371/journal.pone.0280509

Purwani, L. D., Sudargo, F., & Surakusumah, W. (2018). Analysis of student's scientific literacy skills through socioscientific issue's test on biodiversity topics. *Journal of Physics: Conference Series*, *1013*(1), 012019. https://doi.org/10.1088/1742-6596/1013/1/012019

Rahayu, S., & Rosawati, E. E. (2023). The development of higher-order thinking skills (HOTS) assessment instrument in chemistry using socioscientific issues context: A preliminary trial. *AIP Conference Proceedings*, *2572*, 030009. https://doi.org/10.1063/5.0118624

Ram, R. (2020). Engaging young people in science education through socioscientific issues of biosecurity. *Kōtuitui: New Zealand Journal of Social Sciences Online*, *15*(1), 22–37. https://doi.org/10.1080/1177083X.2019.1637908

Rasa, T. (2024). Futurising science education: Technology, agency and scientific literacy. *Nordic Studies in Science Education*, *20*(1), 119. https://doi.org/10.5617/nordina.11429

Rojas-Sánchez, M. A., Palos-Sánchez, P. R., & Folgado-Fernández, J. A. (2023). Systematic literature review and bibliometric analysis on virtual reality and education. *Education and Information Technologies*, *28*(1), 155–192. https://doi.org/10.1007/s10639-022-11167-5

Schenk, L., Hamza, K., Arvanitis, L., Lundegård, I., Wojcik, A., & Haglund, K. (2021). Socioscientific issues in science education: an opportunity to incorporate education about risk and risk analysis? *Risk Analysis*, *41*(12), 2209–2219. https://doi.org/10.1111/risa.13737

Solli, A. (2021). Appeals to science: recirculation of online claims in socioscientific reasoning. *Research in Science Education*, *51*(S2), 983–1013. https://doi.org/10.1007/s11165-019-09878-w

Stoeffler, K., Rosen, Y., Bolsinova, M., & von Davier, A. A. (2020). Gamified performance assessment of collaborative problem solving skills. *Computers in Human Behavior*, *104*, 106036. https://doi.org/10.1016/j.chb.2019.05.033

Tidemand, S., & Nielsen, J. A. (2017). The role of socioscientific issues in biology teaching: from the perspective of teachers. *International Journal of Science Education*, *39*(1), 44–61.

https://doi.org/10.1080/09500693.2016.1264644
Topçu, M. S., Foulk, J. A., Sadler, T. D., Pitiporntapin, S., & Atabey, N. (2018). The classroom observation protocol for socioscientific issue-based instruction: development and implementation of a new research tool. *Research in Science & Technological Education*, *36*(3), 302–323. https://doi.org/10.1080/02635143.2017.1399353
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
UNESCO. (2017). *Education for Sustainable Development Goals: learning objectives*. UNESCO. https://doi.org/10.54675/CGBA9153
Valdez, V. E., & Bianchini, J. A. (2023). "People need to speak up": preservice secondary science teachers' movement toward a justice-centered science education. *Journal of Science Teacher Education*, *34*(5), 497–521. https://doi.org/10.1080/1046560X.2023.2193304
van Lieshout, E., & Dawson, V. (2016). Knowledge of, and attitudes towards health-related biotechnology applications amongst Australian year 10 high school students. *Journal of Biological Education*, *50*(3), 329–344. https://doi.org/10.1080/00219266.2015.1117511
Vesterinen, V.-M., Tolppanen, S., & Aksela, M. (2016). Toward citizenship science education: what students do to make the world a better place? *International Journal of Science Education*, *38*(1), 30–50. https://doi.org/10.1080/09500693.2015.1125035
Yacoubian, H. A., & Khishfe, R. (2018). Argumentation, critical thinking, nature of science and socioscientific issues: a dialogue between two researchers. *International Journal of Science Education*, *40*(7), 796–807. https://doi.org/10.1080/09500693.2018.1449986
Yapıcıoğlu, A. E. (2020). Covid 19 pandemic as a socioscientific issue in science education and suggestions for sample applications. *Journal of National Education*, *49*(1), 1121–1141. https://doi.org/10.37669/milliegitim.787170
Zeidler, D. L., Herman, B. C., & Sadler, T. D. (2019). New directions in socioscientific issues research. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), Article 11. https://doi.org/10.1186/s43031-019-0008-7
Zhdanov, S. P., Akhmedova, M. G., Sokolova, N. L., Grishnova, E. E., Efimushkina, S. V, & Smirnova, L. M. (2023). Exploring preservice science teachers' attitudes toward environmental technologies. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(1), 12825. https://doi.org/10.29333/ejmste/12825
Zhu, Y., & He, A. (2022). The effects of a collaborative argumentation intervention on Chinese students' socioscientific issues decision-making. *The Journal of Educational Research*, *115*(6), 317–332. https://doi.org/10.1080/00220671.2022.2150996
Zidny, R., Solfarina, S., Aisyah, R. S. S., & Eilks, I. (2021). Exploring indigenous science to identify contents and contexts for science learning in order to promote education for sustainable development. *Education Sciences*, *11*(3), 114. https://doi.org/10.3390/educsci11030114
Zulfugarzade, T. E., Chirkina, S. E., Kondrashev, S. V, Chernega, T., Luzin, A., & Tararina, L. I. (2024). A comprehensive bibliographic analysis of environmental education research in Russia. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(4), 14425. https://doi.org/10.29333/ejmste/14425