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Perspectives of Socio-Scientific Issues in Educational Research: A Bibliometric Analysis

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Résumé de l'article

The intricate nature of socio-scientific issues has gained traction among researchers in recent decades. This study explores educational research focused on socio-scientific issues over the last 21 years (2002-2023) using the bibliometric method. The analysis of 350 Scopus-indexed articles was conducted, examining publication trends, influential contributors, and research trajectories through citation, co-occurrence, and co-citation analyses. Co-citation analysis reveals a complex intellectual structure within the field, with a dominant cluster of influential authors and several smaller, specialized research communities emerging. Analysis revealed that the major themes discussed by the examined articles include the nature of science, climate-change decision-making, and education for sustainability, which are crucial in addressing contemporary challenges in education and society. This study highlights the significance of fostering interdisciplinary cooperation and integration of technological aspects into future research. It also identifies the necessity of addressing gaps in research resources, improving knowledge accessibility, and strengthening international collaborations for the field's advancement.

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Abstract

The intricate nature of socio-scientific issues has gained traction among researchers in recent decades. This study explores educational research focused on socio-scientific issues over the last 21 years (2002-2023) using the bibliometric method. The analysis of 350 Scopus-indexed articles was conducted, examining publication trends, influential contributors, and research trajectories through citation, co-occurrence, and co-citation analyses. Co-citation analysis reveals a complex intellectual structure within the field, with a dominant cluster of influential authors and several smaller, specialized research communities emerging. Analysis revealed that the major themes discussed by the examined articles include the nature of science, climate-change decision-making, and education for sustainability, which are crucial in addressing contemporary challenges in education and society. This study highlights the significance of fostering interdisciplinary cooperation and integration of technological aspects into future research. It also identifies the necessity of

addressing gaps in research resources, improving knowledge accessibility, and strengthening international collaborations for the field's advancement.

Introduction

A wide range of disciplines and courses are included in the diversified field of education, all of which support students' intellectual and cultural development (Khotinets & Shishova, 2023; Ladson-Billings, 1995; Piaget, 1964). One of the prominent narratives about education in modern society is that it plays a critical role in shaping the lives of people through a multidisciplinary approach. The multidisciplinary nature of education helps learners to understand complex issues, fosters creativity, and encourages drawing connections between different knowledge structures (Jukola, 2007; Nissani, 1997). Education, as a body of knowledge, is an assemblage of various disciplines. The key ones that contribute to the knowledge of education are philosophy, psychology, sociology, and history. The confluence of knowledge from these disciplinary backgrounds offers critical contributions to understanding and identifying the curricular content, delivery of knowledge, and conduct of assessment. In addition, the integration of sociological, philosophical, and historical elements into education not only enhances knowledge generation (Gunasekaran et al., 2022; Özcan & Balım, 2021), but also develops critical thinking and problem-solving abilities (Molinatti et al., 2010). This approach emphasizes the necessity of intertwining various fields to create a comprehensive, culturally-relevant, educational experience that equips students for complex real-world challenges. Socio-scientific issue-based education is one of the innovative approaches that show promise in this area of pedagogical transformations. Science is a robust knowledge system, across history, which has meddled with conventional thoughts. The way that science is produced, and the way it is further discussed is an intricate matter of concern.

In order to foster scientific literacy and provide students with the tools that they need to make wise decisions, socio-scientific-issues-based instruction incorporates social, ethical, and environmental topics into science lessons. "Social dilemmas with conceptual or technological links to science" are known as SSI (Sadler, 2004a). These dilemmas are usually controversial, real-world problems that are ill-structured (Chowdhury et al., 2020; Sadler & Zeidler, 2005b; D. Zeidler, 2015). Socio-scientific issues include concerns about environmental conservation, such as the protection of flora and fauna, pollution of water, air and soil, man-made disasters, etc. Several studies have been carried out on the SSI paradigm, shedding light on how effective SSI is as a powerful agent for science transactions (Badeo & Duque, 2022; Cavagnetto, 2010; Dawson & Venville, 2010; Evren-Yapicioglu, 2018; Grace, 2009; Kumar et al., 2024; Osborne et al., 2004; Ratcliffe & Grace, 2005; Sadler & Zeidler, 2005a; Simonneaux & Simonneaux, 2009; D. L. Zeidler et al., 2009a). The argument's empirical justification has been investigated in a number of research studies. The divergent nature of SSI is due to societalproblems, which have a link to science and technology.

It is crucial to recognize the trends and patterns in research efforts focused on socio-scientific issues. One can identify the roots of SSI in educational research, which is evident from the path-breaking researchers like Sadler and Zeidler(Ban & Mahmud, 2023; Barzilai & Chinn, 2020; Sadler, 2004a, 2004b, 2009, 2011a, 2011b; Sadler & Zeidler, 2004, 2005a; Tang et al., 2024; D. L. Zeidler et al., 2009b). Even though the root of this construct was educational research, it is discussed widely in different disciplines. The researchers intend to explore the scope of bibliometric analysis in the area of socio-scientific issues focused on educational research, which would help in analysing the ongoing trends in an area, and to identify their intellectual base. This

analysis focused on educational research related to this subject over the period of 2002-2023, and valuable insights were garnered, which can contribute to the evolving landscape of this innovative pedagogical approach. The findings will shed light on the influential publications, prominent authors, and emerging trends shaping the discourse surrounding educational research focused on SSI. The influential publications based on the normalized citation help in identifying the key topics and research questions emanating out of this topic, and the way in which these questions are answered. In addition to the generation of new knowledge, this would help in understanding the methods of research that evolve out of the research questions. Identification of the prominent authors helps in discovering their critical contributions and the backgrounds that shaped their scholarship. The emerging trends in the area of educational research focused on SSI would enable the researchers to set their focus for future studies, and also develop a sensitivity for identifying issues around them that are socio-scientific in their basic nature. Given the multidisciplinary feature of this field, and its potential impact on fostering scientific literacy and decision-making skills, a comprehensive understanding of the research patterns and citation dynamics is crucial. Existing research literature with a bibliometric focus on this area is less in number.The findings of this bibliometric study can inform future research directions, identify potential collaborations, and highlight areas that require further exploration within the research landscape of educational research focused on SSI.

In this context, to guide this analysis and uncover critical aspects of the field's development, the following research questions were posed:

RQ 1. Who are the most cited authors in educational research focused on socio-scientific issues over the past 21 years?

RQ 2. Which countries have the most significant educational research publications focused on socio-scientific issues during the last 21 years?

RQ 3. Which are the most cited research papers in educational research focused on socio-scientific issues over the past 21 years?

RQ 4. Which are the most cited sources/journals in educational research focused on socio-scientific issues over the past 21 years?

RQ 5. What are the keywords frequently used by authors in educational research focused on socio-scientific issues during the last 21 years?

RQ 6. Which research documents are co-cited most frequently by authors in educational research focused on socio-scientific issues over the past 21 years?

Method

In the present study, literature related to educational research efforts focused on socio-scientific issues is examined using bibliometric analysis, which uses a quantitative lens to view the existing literature in a chosen field to find patterns in trends, social networks, and research gaps (Dede & Ozdemir, 2022; José de Oliveira et al., 2019; Wirzal et al., 2022). This thorough evaluation of metadata helps to identify the most influential articles, authors, themes, and institutions that promote studies related to SSI (Van Raan, 2003). The details of the data collected and the analytical procedure are explained in the subsequent sections.

Table 1: Inclusion and exclusion criteria.

	Inclusion Criteria	Exclusion Criteria
Publication Year	articles published from January 2002 to December 2023	articles published before January 2002
Document Type	articles	conference paper, book chapter,
Source type	journal	conference proceedings, books, book series, trade journals, and undefined
Language	English	languages other than English

Data collection

Metadata for bibliometric analysis, related to educational research, focused on socio-scientific issues, and was retrieved from the Scopus database. Scopus is considered, since it has been accepted as one of the primary bibliographic sources of information (Aghaei Chadegani et al., 2013; Mongeon & Adèle Paul-Hus, 2016). It has more published works related to social sciences, compared to other databases, like the Web of Science (Gao et al., 2022; Narong & Hallinger, 2024). Also, Scopus is more compatible with the most widely used bibliometric software, such as Biblioshiny, Gephy, and VOSviewer (Tomaszewski, 2023).

There are two methods for collecting the appropriate bibliometric data in a chosen field of study: a search for a selected keyword and a search for articles published in one or several specific journals (Zupic & Čater, 2014). To cover as many articles in educational research that focused on socio-scientific issues as possible, the selected keyword search approach was chosen for the present study. It was initiated using the term "socio-scientific issue." Further filtering was applied using Boolean operators (AND, OR) and default filtering options that are listed in the Scopus database, such as document type, source, and subjects. The data-collection process began by defining the inclusion and exclusion criteria, as detailed in Table 1. These criteria were aligned with the study's purpose of maximizing the number of articles in educational research that focused on socio-scientific issues. Articles written in English were considered, for two reasons: the status of English as the primary language in socio-scientific academic publishing and the comfort of the researchers to read and write in the English language. The selection of the English language ensured consistency across the analysis of articles and could improve accessibility for the broader research community. The document type was restricted to "articles," and the source type was limited to "journals," using filters in the Scopus database. The timeframe of 2002 to 2023 was determined, due to the availability of articles based on the search string. The search results automatically covered publications from January 2002 to December 2023, providing a comprehensive overview of the research landscape of educational research that focused on socio-

scientific issues over the past 21 years. The process of data collection is illustrated in Figure 1, and it followed PRISMA standards (Moher et al., 2010). The search generated 1215 documents, which were exported as a comma-separated value (.CSV) file for analysis using MS Excel and the VOS viewer toolkit. A total of 865 documents were excluded, because they did not meet the inclusion criteria.

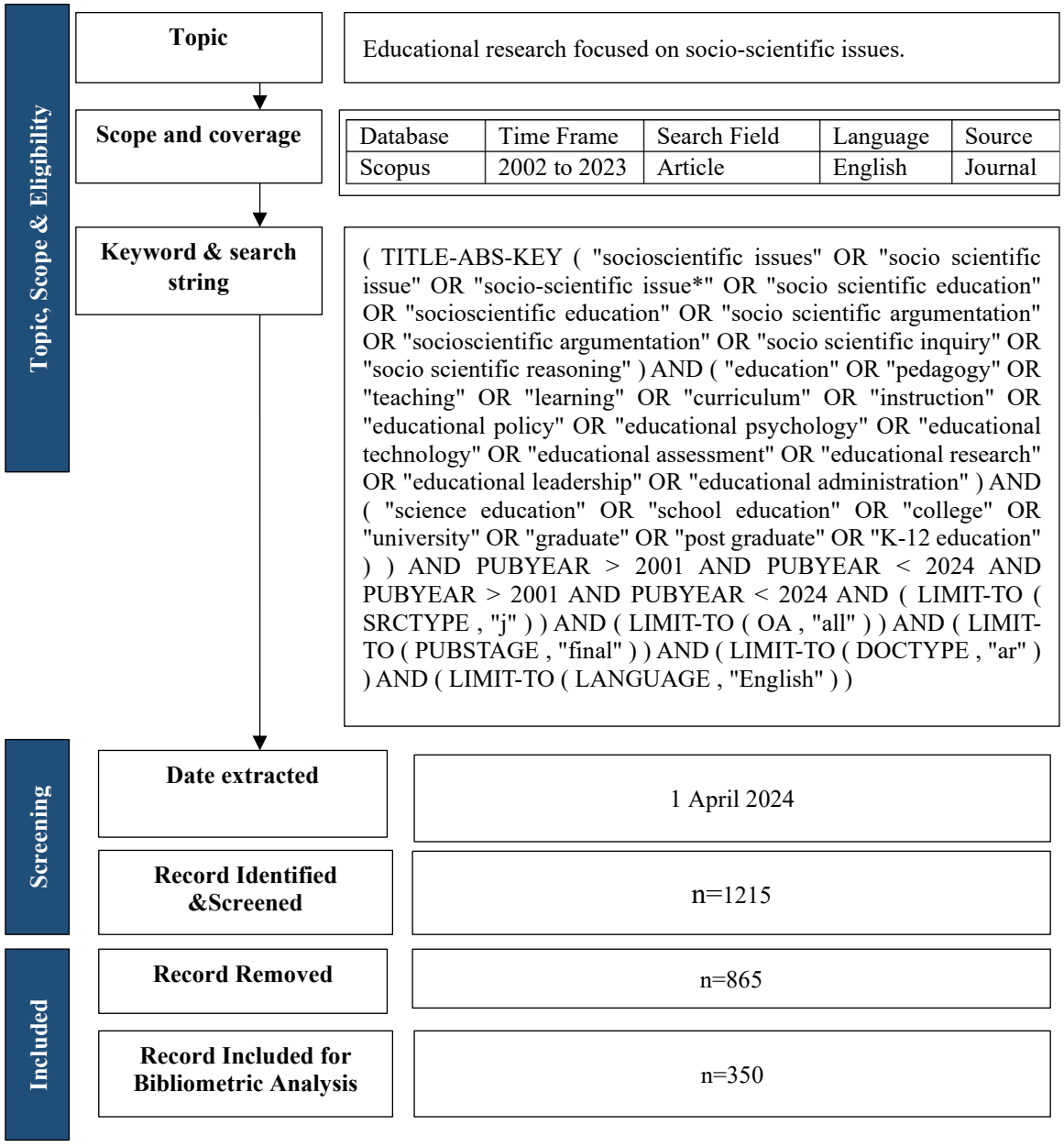

Figure 1: Process of data collection *(Kavitha & Joshith, 2024; Zakaria et al., 2021).*

Data screening and cleaning

There is a chance that bibliometric data may consist of duplicates, keyword errors, and missing entries. Hence, data screening was carried out to obtain more reliable results. The editable format (.CSV) of bibliometric data provides the opportunity to curate mistakes, duplicates, and

keyword errors before analysis. To develop the thesaurus file, researchers began using VOSviewer, which was then used to create a map, with the keywords exported to a text file containing essential information, such as keyword occurrences and link strengths. The exported file was then opened in Microsoft Excel, where researchers filtered out irrelevant columns to focus solely on the keywords. A two-column table was created with the headers "label" and "replace by" to facilitate consistent terminology. Each original term was listed in the "label" column, with preferred replacements specified in the "replace by" column, or left blank, if removal was desired. For example, "Hong Kong" was standardized as "China." Terms with similar meanings were merged, in order to enhance clarity and thematic consistency. Final adjustments were made by consolidating redundant terms, and applying preferred singular forms to maintain uniformity. The thesaurus was saved as a plain text file (.txt) for integration back into VOSviewer. This process allowed for a refined and comprehensive list of terms, optimising the quality of subsequent bibliometric analyses (Jan van Eck & Waltman, 2023).

Verification steps were performed to validate the thesaurus files created. Initially, maps were generated using VOSviewer, both with and without the thesaurus file, to assess differences in keyword clustering and term visibility. This comparison allowed for the identification of any terms that were still missing or ambiguously grouped. Threshold adjustments were tested within VOSviewer to ensure relevant terms were neither omitted, nor redundantly included. In addition to this, researchers reviewed the revised clusters and maps with other researchers to confirm that the chosen terms and replacements aligned with common usage in the literature (Jan van Eck & Waltman, 2023; Lim et al., 2024).

While considering the data for citation analysis with countries, the number of countries listed initially was 64. However, during the data screening process, we identified specific errors in the data set, which omitted five entries, including, biology, Educação, institute for biology, Instituto de educação, and technology. Additionally, Hong Kong was listed among the countries, and it is relabeled as China. Finally, 58 countries were selected for further analysis.

In the dataset considered for the co-citation analysis, several typographical errors and inconsistencies were identified. These included differences in the presentation of journal details, authors' names, and publication titles. For example, entries such as "driver r., newton p., osborne j., establishing the norms of scientific argumentation in classrooms, science education, 84, pp. 287-312, (2000)" exhibited slight variations. To ensure accuracy and uniformity, these errors were rectified, and entries with only slight variations were combined. For instance, various versions of "Sadler t.d., Barab s.a., Scott b., What do students gain by engaging in socioscientific inquiry?, research in science education, 37, 4, pp. 371-391, (2007)" were matched and merged. The curation process was completed using a thesaurus file.

Data analysis

This study involves a bibliometric analysis to examine the educational research landscape focused on socio-scientific issues. The data was retrieved from Scopus using a specific search query, mentioning the keywords, document type, year of publication, access status, etc. (See Figure 1). The resulting CSV file, containing comprehensive information on 350 articles, served as the data source. VOSviewer, an open-source software tool with a user-friendly interface and better clustering functionality (Cobo et al., 2011), was used to generate visual maps based on this bibliometric data. Additionally, the MS Excel toolkit was used for corresponding analytical research. The analysis included two main components: performance analysis and bibliometric mapping. Performance analysis examined research elements, like the total number of citations, publications by author, and average citations per article per year. These metrics provide insights

into researcher influence and productivity in the field. Bibliometric or science mapping explores the structure and evolution of knowledge in the research area (Bayer et al., 1990; Hota et al., 2020; Yang & Liu, 2022). An important deficiency of this table is that it did not offer an understanding of the connections among the research components and the strength of the relationship among them. The visual maps generated using the VOSviewer address this limitation of the performance analysis table. Considering this, in the present study, the VOS viewer was used to generate the visual maps, based on the bibliometric data. These maps provided a detailed understanding of the connections among research components and the strength of their relationships. Citation analysis revealed the most prominent and influential authors, publications, and sources/journals. Co-citation analysis illustrates the network of authors who crafted foundational and influential articles, and it also explores the foundational documents, which are the intellectual base of a specific research area. Keywords that are prominent in this research landscape were identified through co-occurrence analysis. The study utilized quantitative performance metrics and visual mapping techniques to investigate the evolution of educational research literature that focused on socio-scientific issues over the past 21 years (2002-2023). This analysis helped the researcher to answer the research questions set for the study.

Results and Findings

Major results and findings are presented in this section.

Volume and distribution of documents across years and countries

The general statistics of the data regarding articles are initially explored by focusing on the volume and distribution across years and countries. Figure 2 illustrates the yearly breakdown of documents and citations related to educational research efforts addressing socio-scientific issues from 2002 to 2023. Observing the trend, volatility in the number of documents and citations over the years is evident. There was only one publication in 2002, which will grow exponentially to reach 68 in 2021. No documents were recorded from 2003 to 2006. The number of citations has also grown, from 297 in 2002 to a peak of 537 in 2010. The crucial years in this data appear to be 2019 and 2020, which saw a significant spike in documents (31 and 38, respectively) and citations (497 and 380, respectively). This suggests that these years have been pivotal in terms of publishing activity related to socio-scientific issues based educational research.

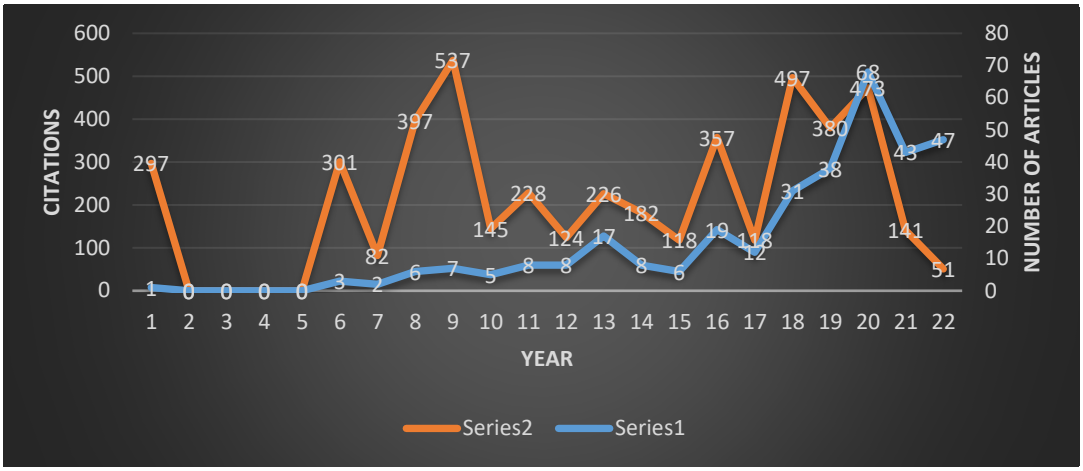

Figure 2: The total number of publications and citations by year.

No documents were recorded between the years 2003 to 2006, highlighting a decline in publications related to educational research focused on SSI. A separate manual review was conducted to investigate the wane in publication trends, focusing on the period from 2003 to 2006. Significant changes in the number of publications for these years were noticed, when certain filters were altered. Therefore, the "open access" and language filters were removed to allow for a more comprehensive review, capturing all relevant articles, regardless of their access status or language. This approach ensured that no potentially significant publications were overlooked, providing a clearer picture of the research activity during these years. This review identified 24 articles, 22 written in English and not classified as "open access." The finding highlights the restrictions on knowledge acquisition, as retrieval of these articles may be restricted by financial barriers (Ignatow & Robinson, 2017; Mariotti, 2022). The two non-English articles, in French and Portuguese, were included in the "open access all" category. Notably, 2003 remains a year with no recorded publications. The overall pattern is cyclical, with peaks and valleys in documents and citations. However, the general trajectory is one of growth, indicating an increasing level of interest and activity in this field over the past 21 years.

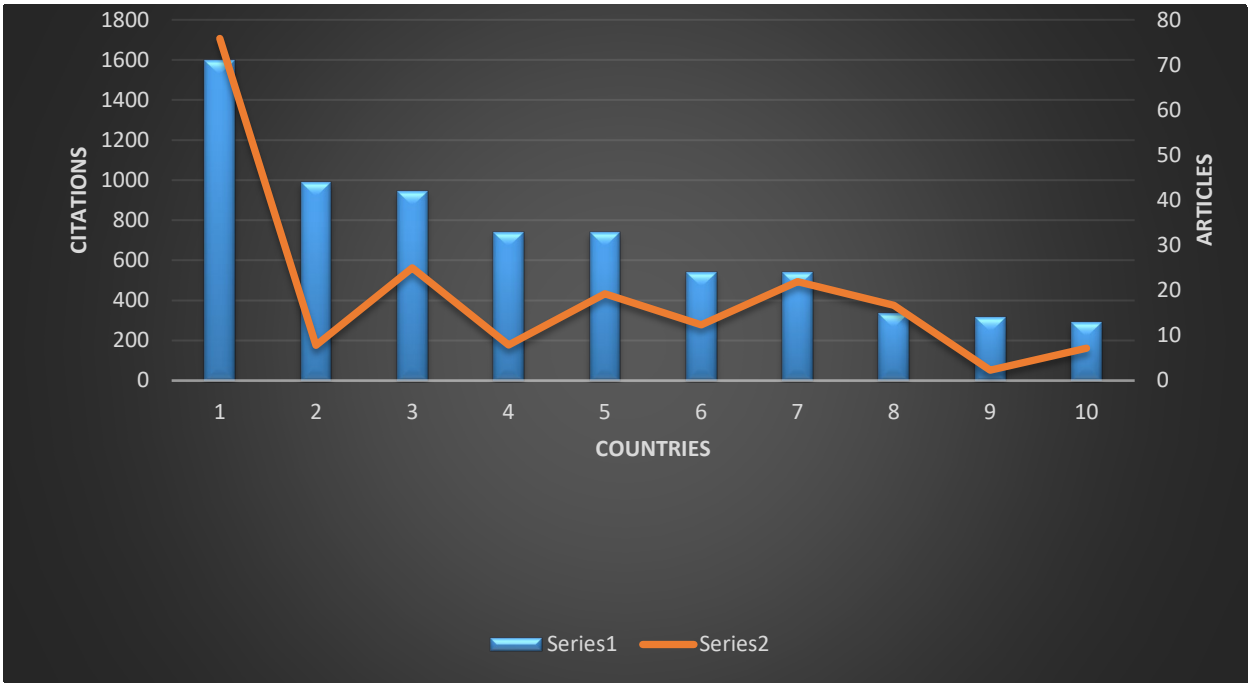

Figure 2: Country-wise publication trajectory.

The global terrain of research output is revealed through an analysis of the distribution of documents across various countries. The United States leads significantly, contributing 71 documents during the period of 2002-2023, indicating its dominant position in the number of publications. Turkey and Germany are prominent contributors, with 43 and 41 documents, respectively. Indonesia (33 documents) and Sweden (32 documents) also show vigorous research activities. Countries like the United Kingdom (24 documents) and Spain (23 documents) have substantial, but comparatively lower outputs, indicating active, but fewer publications in educational research focused on SSI. South Korea (14 documents), Australia (15 documents), and

the Netherlands (12 documents) are notable contributors, reflecting their involvement in the global research community.

Country-wide analysis revealed that Cyprus has a high amount of citations (197), relative to document count (7), indicating a high impact with fewer publications. Additionally, the number of documents (33) and citations (178) in Indonesia marks it as one of the countries where SSI is an emerging research site. Citation counts have limits, even though the small number of citations (3) for the six Malaysian documents might point to issues with the prominence or quality of the research. (Ebrahim et al., 2013). Citation counts can be influenced by particular discipline citation styles, age of publications, and field of research (Tahamtan et al., 2016; Wheeler et al., 2022). Further analysis of the study areas, sites for publication, and collaborations among Malaysian researchers in this field may shed light on the causes of the lesser impact of citations (Haddow & Genoni, 2010). Countries like Argentina, Belgium, Georgia, Iran, Japan, Jordan, Kyrgyzstan, Mexico, Mozambique, Panama, Poland, and Uruguay, each with only 1 document, suggest minimal contributions, which could be due to educational research that is focused on socio-scientific issues has not been a great concern in these countries. Mozambique, Panama and Uruguay were reported as countries with no citations.

This data exposes a significant hegemony in publication by the United States, followed by European countries like Germany, the United Kingdom, and Turkey. This dominance indicates a concentration of research resources and infrastructure in these regions. The disparity in publication output highlights the uneven distribution of concerns over SSI, research facilities, and opportunities for publications in indexed research journals compared to developed countries leading in research contributions.

Citation analysis with authors

To identify the most influential authors in educational research, those who focus on socioscientific issues, a citation analysis was performed. The minimum requirement was set to at least one document and one citation, and documents with numerous authors were omitted. The maximum number of authors per document is set as 25. Based on these criteria, 746 authors were selected out of 895 and were considered for further analysis. Three-hundred-sixty-seven (367) writers with the highest link strength among the 746 authors were considered for science mapping and performance analysis. Table 2 arranges the top 20 writers according to the total number of citations and displays of their performance values. TroyD. Sadler emerges as the most prominent author in the research related to socio-scientific issues, having the highest citations and norm citations with this count of 573, with an average of 63.66 per document. These citation metrics demonstrate his multiple publications' consistent and significant impact, with a notable normalized citation of 2.68.

As seen in Table 2, the three most productive authors in the field are Troy D. Sadler, Ingo Eilks, and Maria Evagorou, with 9, 14, and 4 publications, respectively. When considering the average year of publications, these authors emerge as the most recently active ones. The analysis reveals that the most influential writers of this topic, based on total citations, are Troy D. Sadler, Dana L. Zeidler, and Wayne A. Ackett, with total citations of 573, 544, and 297, respectively.

Table 2: The most cited 20 authors.

Sl. No	Author	Document	Citation	Avg. Citation	Norm Citation	Avg. Norm Citation	Avg. Pub.Year
1	Troy D.Sadler	9	573	63.66	24.15	2.68	2017
2	Dana L.Zeidler	5	544	108.8	7.9	1.58	2014
3	Wayne A.Ackett	1	297	297	1	1	2002
4	Michael L.Simmons	1	297	297	1	1	2002
5	Kimberly A.Walker	1	297	297	1	1	2002
6	Andy R.Cavagnetto	1	264	264	3.44	3.44	2010
7	Ingo Eilks	14	253	18.07	20.11	1.43	2019
8	Sasha A.Barab	1	200	200	1.99	1.99	2007
9	Conan Heiselt,	1	200	200	1.99	1.99	2007
10	Daniel Hickey,	1	200	200	1.99	1.99	2007
11	Steven Zuiker	1	200	200	1.99	1.99	2007
12	Scott Applebaum	1	180	180	2.72	2.72	2009
13	Brendan E. Callahan	1	180	180	2.72	2.72	2009
14	Marcus Grace	5	154	30.8	6.01	1.202	2015
15	Maria Evagorou	4	131	32.75	9.57	2.3925	2019
16	Vaille Maree Dawson	1	127	127	1.66	1.66	2010
17	Grady Venville	1	127	127	1.66	1.66	2010
18	Laura Zangori	2	120	60	10.95	5.475	2019
19	Patricia J. Friedrichsen	2	101	50.5	8.03	4.015	2020
20	Jan Alexis Nielsen	2	96	48	4.66	2.33	2014[i]

Normalized citations, which evaluate the number of citations per article against the average of those of all articles published in the same year, indicate that Troy D. Sadler (2.68), Laura Zangori (5.475), and Patricia J. Friedrichsen (4.015) are among the top influential authors. Troy D. Sadler's high average normalized-normalized citations (2.68) imply that his work is consistently recognized and cited by peers. In contrast, Laura Zangori's higher score (5.475) reflects her substantial impact, despite having fewer publications. Patricia J. Friedrichsen's score (4.015) indicates a balanced mix of productivity and influence. Figure 4 depicts the overlay visualisation of authors based on average norm citations. Each node's size, in this picture, represents the total number of citations the author has received, and each node's colour represents the average normalized-normalized citation score. In essence, the colours of the nodes represent the level of influence that writers have in educational research that is focused on socio-scientific issues. The authors who are coloured yellow are the most influential, while those who are coloured

blue are less prominent (Dede & Ozdemir, 2022; Jan van Eck & Waltman, 2023). The analysis highlights that while some authors have numerous total citations, their influence, as measured by normalized citations, might differ. For example, Wayne A. Ackett (297), Michael L. Simmons (297), and Kimberly A. Walker (297) have high total citations, but lower normalized-normalized citation scores (1, 1, 1, respectively), indicating that their impact might be concentrated in specific high-citation works, rather than consistently influential publications. This trend could be due to seminal papers that garner significant attention, but are not followed up by a series of impactful works. Conversely, authors like Ingo Eilks (253 total citations, 20.11 normalised-normalized citations) and Laura Zangori (120 total citations, 10.95 normalized-normalized citations), with moderate total citations, show vital average normalised citations, indicating a broader impact across their publications. This pattern suggests that their contributions are widely acknowledged in the field, supporting sustained academic influence.

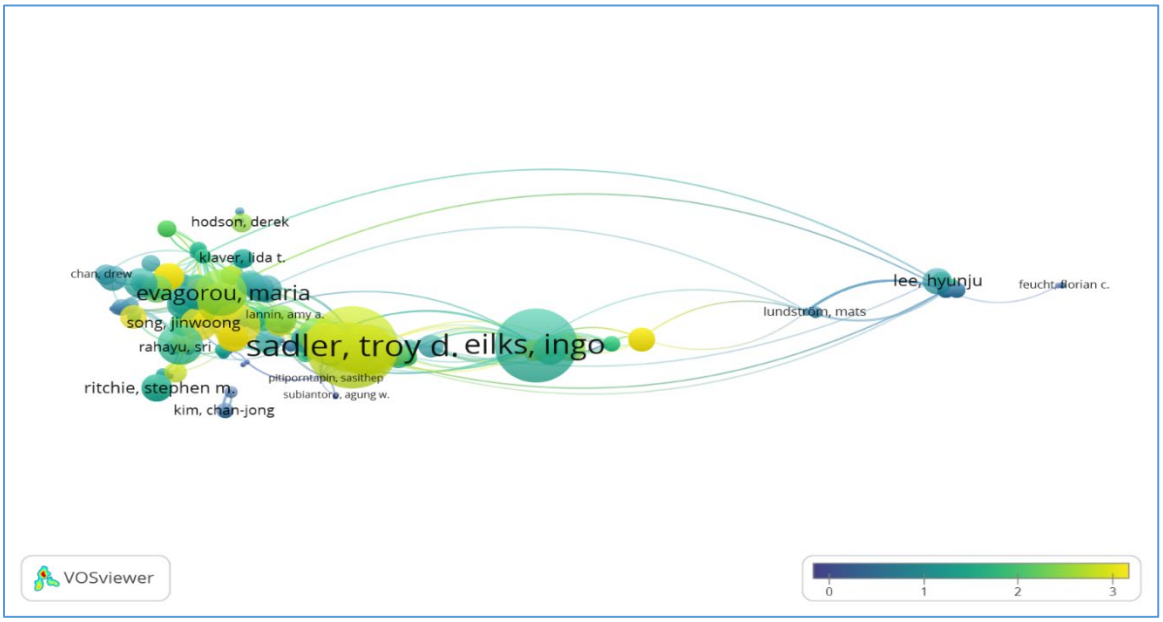

Figure 3: Overlay visualization of authors (average norm citations).

Citation analysis with sources

A citation analysis of 350 articles based on their sources was conducted. The top 15 highly cited journals were tabulated in Table 3. The table comprises the names of prominent journals and metrics like the number of documents, citations, h-index, and quartile value (Q value). Citation analysis reveals the significant reach and influence of the journals within the academic community. The highly cited journals, such as the "International Journal of Science Education" (909 citations), "Journal of Research in Science Teaching" (390 citations), and "Science and Education" (320 citations), demonstrate their ability to disseminate high-quality research that resonates with scholars worldwide.

Table 3: Citation analysis with sources.

Sl.No	Source	Documents	Citations	h index	Q value	Avg. Pub Year
1	International Journal of Science Education	34	909	126	Q1	2014
2	Journal of Research in Science Teaching	10	390	157	Q1	2018
3	Science And Education	20	320	58	Q1	2021
4	Science Education	3	303	135	Q1	2015
5	Review Of Educational Research	1	264	186	Q1	2010
6	Eurasia Journal of Mathematics, Science and Technology Education	22	252	56	Q2	2018
7	Research In Science Education	11	241	67	Q1	2018
8	Journal Of Science Education and Technology	1	200	80	Q1	2007
9	Studies In Science Education	3	167	54	Q1	2012
10	Cultural Studies of Science Education	10	135	41	Q1	2017
11	Sustainability	22	114	169	Q1	2022
12	Ensenanza De Las Ciencias	6	73	22	Q2	2017
13	Frontiers In Education	15	68	40	Q2	2021
14	Education Sciences	9	66	53	Q2	2021
15	Learning And Instruction	2	64	144	Q1	2018[ii]

The table also presents the h-index values, which provide a balanced measure of a journal's productivity and citation impact (Hirsch, 2005). The "Review of Educational Research" (h-index of 186) and "Journal of Research in Science Teaching" (h-index of 157) stand out as having both a high h-index and a significant number of citations, indicating their consistent publication of influential and highly-cited research over time.

Science mapping is carried out by defining the criteria of a minimum of one citation and the number of documents per journal. Out of 116 journals, 107 met the criteria, and the top 15 are considered for science mapping. From the selected 15 journals, only 14 items are interconnected. The average publication year of these top 15 sources ranges from 2007 to 2022, reflecting a significant shift in influential research around 2014. This observation aligns with the observed trends, where foundational articles from 2002 to 2012 continue to be heavily cited, and are among the top five most influential articles.

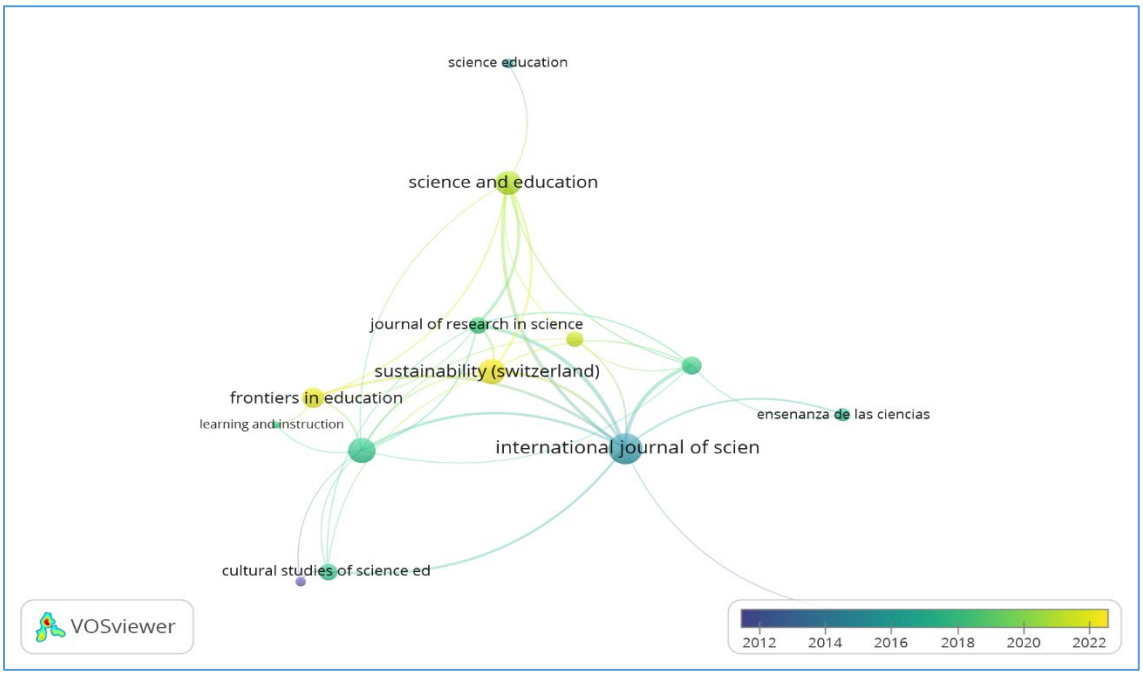

Figure 4: Overlay visualization of 15 most cited journals (average publication year).

One key development during this period (2002-2014) was the SSI framework by Zeidler, Sadler, and their colleagues in SSI-based research (Sadler, 2004a; D. L. Zeidler et al., 2002). Journals with earlier average publication years, like "Review of Educational Research" (Avg. Pub Year 2010, 264 citations, h-index 186) and "Journal of Science Education and Technology" (Avg. Pub Year 2007, 200 citations, h-index 80) have maintained their influence and impact over an extended period, as evidenced by their impressive citation counts and high h-indices. Adding to that, journals with more recent average publication years, such as "Sustainability" (Avg. Pub Year 2022, 114 citations) and "Frontiers in Education" (Avg. Pub Year 2021, 68 citations), have managed to accumulate substantial citation counts within a relatively short period, suggesting their ability to rapidly disseminate timely and relevant research that resonates with the scientific community.

Citation analysis by countries

Citation analysis was done with countries, and a minimum number of documents and citations was set to a minimum of one. Out of 59, only 41 met the threshold. The citation analysis of socio-scientific issues research across various countries reveals significant disparities in productivity and impact. The three most productive countries, measured by the number of documents, are the United States (71), Turkey (44), and Germany (42). Each country exhibits unique characteristics in terms of citations, average citation counts, normalised citations, average normalised citations, and average publication year (see Table 4).

The United States leads in terms of the number of documents (71) and total citations (1707), with an average citation count of 24.04 per document. The country's normalised citation score is 74.53, with an average normalised citation of 1.05, indicating that U.S.-based research is prolific and influential, despite a slightly older average publication year (2018). This finding suggests that

the United States has a well-established presence in the field, with research that continues to garner significant attention over an extended period.

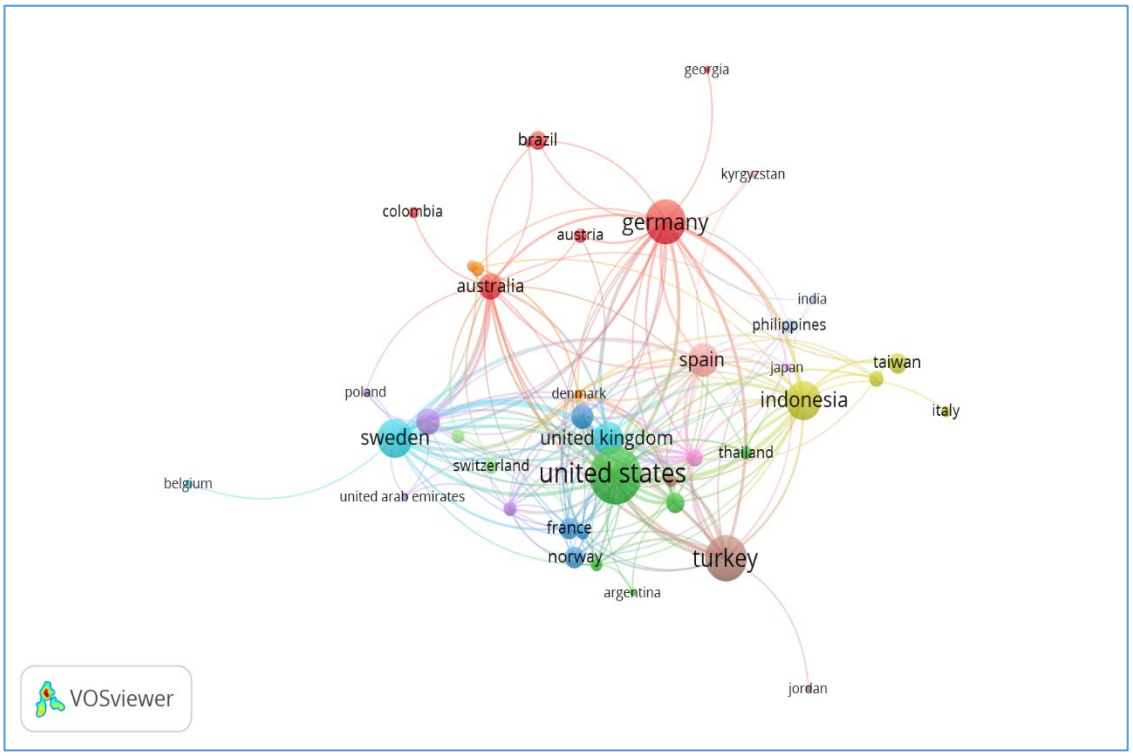

Figure 5: Network visualisation of country-wise citation analysis.

Turkey, the second most productive country with 44 documents, shows a lower total citation count (176) and an average citation count of 4.00 per document. The normalized citation score for Turkey is 26.09, with an average normalised citation of 0.59, indicating a relatively lower impact than other countries. The average publication year for Turkey (2021) is among the most recent, suggesting a newer, but growing contribution to the field, which may yet see increased citations over time.

Germany ranks third, with 42 documents and a total citation count of 562. The average citation per document is 13.38, with a normalized citation score of 63.95 and an average normalised citation of 1.52. Germany's average publication year is relatively recent (2020), reflecting both the productivity and significant impact of German research in the field. The higher normalized citation scores indicate that German research is well-regarded and influential.

Other notable countries include Sweden (33 documents, 433 citations), the United Kingdom (24 documents, 494 citations), and Spain (24 documents, 278 citations). Sweden's average citation per document is 13.12, with a normalized citation score of 33.59 and an average normalized citation of 1.02. The United Kingdom exhibits a higher average citation per document (20.58) and a significant total citation count (494), with a normalized citation score of 31.1 and an average normalized citation of 1.30, highlighting its influential research output. Spain, with an average citation count of 11.58 per document and an average normalised citation of 1.14, demonstrates a noteworthy impact, despite a slightly more recent average publication year (2020). From a critical perspective, the country-wise citation analysis presents a clear picture of regional research strengths and trends. The United States stands out for its prolific and influential research,

a result of its long-standing academic and research infrastructure. Germany and the United Kingdom similarly demonstrate substantial impacts, reflected in their high normalized citation scores, signifying influential research contributions. In contrast, despite their recent and growing contributions, Turkey and Indonesia show lower average citations and normalized citations, suggesting that their research may still be gaining broader recognition and impact.

Table 4: Country-wise citation analysis.

Country	Document	Citation	Avg. Citation	Norm. Citation	Avg. Norm. Citation	Avg. pub Year
United States	71	1707	24.04	74.53	1.05	2018
Turkey	44	176	4.00	26.09	0.59	2021
Germany	42	562	13.38	63.95	1.52	2020
Indonesia	33	178	5.39	31.44	0.95	2021
Sweden	33	433	13.12	33.59	1.02	2018
Spain	24	278	11.58	27.27	1.14	2020
United Kingdom	24	494	20.58	31.1	1.30	2017
Australia	15	375	25.00	17.72	1.18	2017
South Korea	14	52	3.71	11.33	0.81	2021
Netherlands	13	161	12.38	16.6	1.28	2020

The data indicates the importance of productivity and influence in assessing research impact. Countries with a more extended history of research in the field, such as the United States and the United Kingdom, benefit from sustained citation counts over time. Meanwhile, with newer contributions, countries like Turkey and Indonesia may see increased impact as their research gains traction. The average publication year provides context for understanding the temporal aspect of research impact, with more recent publications often requiring time to accumulate citations.

Citation analysis by articles

Citation analysis was done with articles, and the minimum number of citations was set to at least one for the document to qualify for analysis. Out of 350 articles, 292 satisfied the criteria. Among these, 139 articles were used to create the map, as they were the only ones interconnected. According to the methodological approaches utilized in the top 20 most cited publications, 14 papers (70%) employed qualitative procedures (see Figure 7). "'Should we kill the grey squirrels?' A Study Exploring Students' Justifications and Decision-Making" by Evagorou (2012), "Selecting Socio-Scientific Issues for Teaching" by Hancock (2019), "Use of the Concept of Bildung in the International Science Education Literature, Its Potential, and Implications for teaching and learning" by Sjöström (2017), "A Conceptual Analysis of Perspective Taking in Support of Socioscientific Reasoning" by Kahn (2019), and "Science Education and Education for

Sustainable Development" by Eilks (2015) are the top documents, based on their number of citations and norm citations.

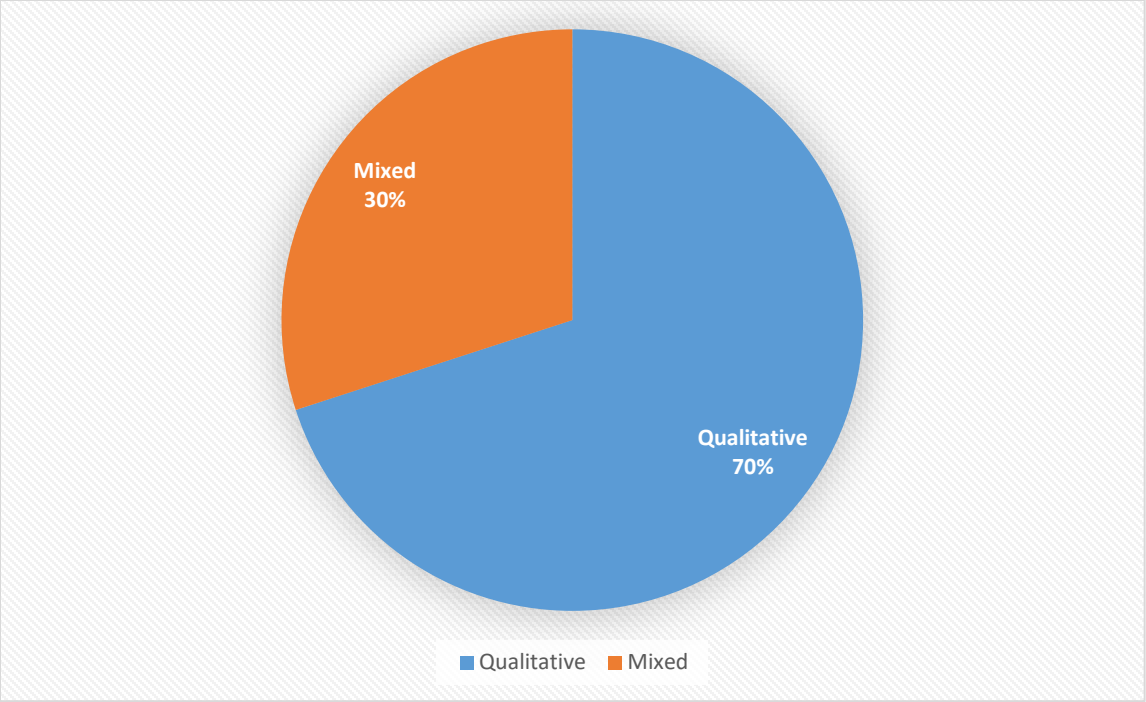

Figure 7: Methodology of the most cited articles.

Six articles (30%) adopted mixed methods, which combined qualitative and quantitative approaches. The mixed-methods studies include: "Developing pre-service teachers' evidence-based argumentation skills on socio-scientific issues" by Iiordano (2014), "Student development of model-based reasoning about carbon cycling and climate change in a socio-scientific issues unit" by Zangori (2017), and "Argument to Foster Scientific Literacy: A Review of Argument Interventions in K-12 Science Contexts" by Cavagnetto (2010).

The field of science education research has produced diverse influential publications, as evidenced by these analyses. Among the most highly cited articles are Cavagnetto's (2010) review on "argument interventions" with 264 citations, Zeidler's (2002) exploration of "beliefs in the nature of science" with 297 citations, and Barab's (2007) study on "supporting consequential play", which has received 200 citations. However, when considering the normalized citation scores as a measure of relative impact, Ke's (2021) work on "Promoting scientific literacy in the context of socio-scientific issues" emerges as the mostprominent , with a normalized citation score of 7.04. Iordano's (2014) research on "Pre-service teachers' argumentation skills" follows with a normalized citation score of 4.21, and Zangori's (2017) investigation into student development of model-based reasoning about carbon cycling and climate change in a socio-scientific issues unit," scoring 3.78. These findings highlight the diverse range of influential topics and methodologies shaping the contemporary discourse in science education, from intervention-focused studies to those exploring the complex reasoning processes of students within socio-scientific contexts.

While citation counts are often used as a metric to gauge the influence and impact of academic works, a closer examination of the data reveals that relying solely on raw citation counts

can be misleading. Despite having the highest overall citation count of 297, the article "Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas" by Zeidler (2002) has a relatively low normalised citation score of 1.0. This metric suggests that while the article has accumulated a significant number of citations over time, its impact may not be as substantial, when considering the age of the publication and citation patterns within the discipline. While mixed-method studies can claim representation among highly cited works and a presence among impactful studies within the research domain, it is crucial to examine the extent and implications of these claims critically. The data shows that two mixed-method studies, "Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas" by Zeidler (2002) and "Argument to Foster Scientific Literacy: A Review of Argument Interventions in K–12 Science Contexts" by Cavagnetto (2010), have garnered the highest overall citation counts. However, it is essential to recognize that citation counts alone do not necessarily equate to impact or significance. The study by Zeidler (2002), despite having the highest citation count, has a relatively low normalized citation score of 1.0, suggesting that its affect may not be as substantial, when accounting for the disciplinary field in which the publication is made, the age of the publication, and document type (research articles in this study) citations of the publication. Conversely, the more recent qualitative study by Ke (2021) has a remarkably high normalized citation score of 7.04, indicating its potential for significant contributions and relevance within a shorter timeframe.

Table 5: Most influential articles.

Author	Titles	Citations	Norm citations	Methodology
Ke (2021)	Developing and Using Multiple Models to Promote Scientific Literacy in the Context of Socio-Scientific Issues	49	7.04	Qualitative
Iordanou (2014)	Developing Pre-Service Teachers' Evidence-Based Argumentation Skills on Socio-Scientific Issues	56	4.21	Mixed
Zangori (2017)	Student Development of Model-Based Reasoning About Carbon Cycling and Climate Change in a Socio-Scientific Issues Unit	71	3.78	Mixed
Tidemand (2017)	The Role of Socioscientific Issues in Biology Teaching: From the Perspective of Teachers	71	3.78	Qualitative
Sjöström (2017)	Use of the Concept of Bildung in the International Science Education Literature, Its Potential, and Implications for Teaching and Learning	66	3.51	Qualitative
Cavagnetto (2010)	Argument to Foster Scientific Literacy: A Review of Argument Interventions in K–12 Science Contexts	264	3.44	Mixed
Evagorou (2012)	'Should We Kill the Grey Squirrels?' A Study Exploring Students' Justifications and Decision-Making	93	3.26	Qualitative

Hancock (2019)	Selecting Socio-Scientific Issues for Teaching	52	3.24	Qualitative
Kahn ((2019)	A Conceptual Analysis of Perspective Taking in Support of Socioscientific Reasoning	48	2.99	Qualitative
Zeidler (2009a)	Advancing Reflective Judgment Through Socioscientific Issues	180	2.72	Mixed
Eilks (2015)	Science Education and Education for Sustainable Development – Justifications, Models, Practices and Perspectives	55	2.42	Qualitative
Tomas (2016)	Students' Regulation of Their Emotions in a Science Classroom	46	2.34	Mixed
Barab (2007)	Relating Narrative, Inquiry, and Inscriptions: Supporting Consequential Play	200	1.99	Qualitative
Dawson (2010)	Teaching Strategies for Developing Students' Argumentation Skills about Socioscientific Issues in High School Genetics	127	1.66	Qualitative
Furberg (2008)	Students' Meaning-Making of Socio-Scientific Issues in Computer-Mediated Settings: Exploring Learning Through Interaction Trajectories	59	1.44	Qualitative
Grace (2009)	Developing High-Quality Decision-Making Discussions about Biological Conservation in a Normal Classroom Setting	91	1.38	Mixed
Zeidler (2002)	Tangled Up in Views: Beliefs in the Nature of Science and Responses to Socioscientific Dilemmas	297	1	Mixed
Simonneaux (2009)	Students' Socio-Scientific Reasoning on Controversies from the Viewpoint of Education for Sustainable Development	63	0.95	Qualitative
Hingant (2010)	Nanosciences and Nanotechnologies Learning and Teaching in Secondary Education: A Review of Literature	56	0.73	Qualitative
Meisner (2007)	Exhibiting Performance: Co-participation in Science Centres and Museums	63	0.63	Qualitative

Co-occurrence analysis

Co-occurrence analysis explores the connections and relationships between the key concepts, themes, and prominent keywords within the research landscape. By analysing the co-

occurrence patterns, the researchers could pinpoint the central and most impactful topics shaping educational research that addresses socio-scientific issues.

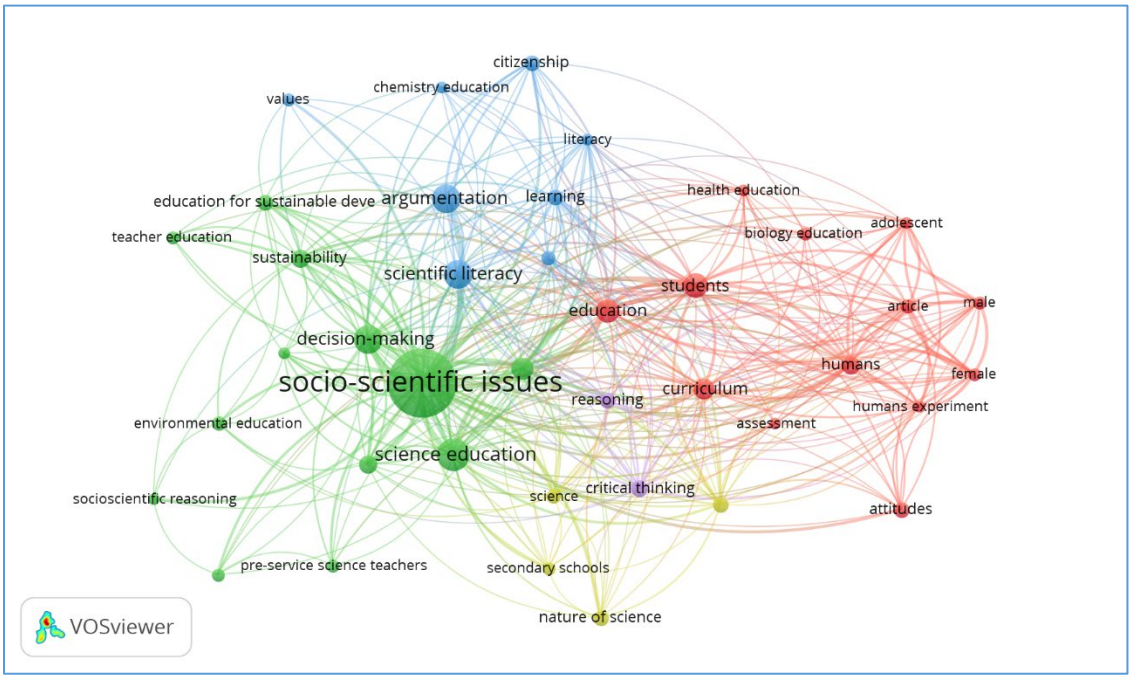

Figure 8: Network visualization of most co-occurred keywords.

Co-occurrence analysis using all the keywords was done using VOSviewer. The threshold for a minimum number of occurrences of keywords is set to six, since the researcher intended to analyze socio-scientific issues in detail, and the number of keywords in total is 1115, which is comparatively less than other research topics. To have a comprehensive view, the occurrence threshold is set to six after a thorough discussion among the researchers. A major argument in favour of this number as a threshold was that it would ensure a visual network that is not too cluttered, or too sparse. Additionally, keeping this threshold ensures the balance between inclusivity and relevance, and it helps reduce the noise due to the least (less than six) mentioned keywords, thereby helping to reduce the computational complexity. Setting an occurrence threshold of this number can help reduce the keywords to a manageable level, making it computationally efficient and faster to complete. Out of the total keywords (1115), 3.58 % (40) satisfied the criterion and are used to create a visual network, illustrated in Figure 8. Keywords frequently appearing in educational research efforts focused on socio-scientific issues are denoted by the nodes in the network.

A total of 40 keywords are distributed in the network, and the size of the nodes indicates the number of occurrences of specific keywords across different studies. The lines between the two nodes suggest the co-occurrence of those connected keywords in a study, and the node's colour is considered a label for which cluster they belong. The most common keywords in educational research related to socio-scientific issues are tabulated in Table 6.

The keyword co-occurrence analysis, sorted by average normalised citations, provided a comprehensive view of research trends and significance within the academic literature. The analysis focused on 15 prominent keywords, revealing distinct insights based on their frequency, average citations, normalised citations, and publication years. The keyword, "nature of science,"

stands out, with an average normalised citation of 1.71 and an average citation of 27.2, indicating that it is highly influential in research with substantial academic impact. Similarly, "education for sustainable development" also shows significant influence, with a normalised citation of 1.66 and an average citation of 24.36, despite having an average publication year of 2017, suggesting sustained relevance over time.

Table 6: Most influential keywords.

Sl.No	Keywords	Occurrences	Average citations	Avg. Norm Citations	Avg.Pub Year
1	Nature of Science	10	27.20	1.71	2020
2	Education For Sustainable Development	11	24.36	1.66	2017
3	Student	27	18.63	1.42	2020
4	Climate Change	15	13.80	1.41	2021
4	Literacy	6	46.50	1.40	2020
6	Sustainability	14	8.07	1.24	2021
7	Curriculum	18	20.78	1.22	2018
8	Critical Thinking	12	11.25	1.17	2019
9	Education	24	13.08	1.14	2020
10	Argumentation	34	13.82	1.10	2018
11	Scientific Literacy	34	12.47	1.06	2019
12	Teaching	20	12.90	1.03	2020
13	Socio-Scientific Issue	200	11.03	0.99	2019
14	Decision-Making	34	12.29	0.94	2019
15	Science Education	45	17.02	0.92	2018

Keywords like "students" (27 occurrences) and "science education" (45 occurrences) appeared the most. However, their average normalized citations are relatively modest, at 1.42 and 0.92, respectively, suggesting that while these topics are widely discussed, their contributions are more incremental, rather than groundbreaking. Emerging trends are evident in keywords such as "climate change" and "sustainability," with recent average publication years (2021) and growing academic interest. Their normalized citations (1.41 and 1.24) indicate that these fields are still evolving, but are increasingly becoming focal points of research. The overlay visualisation of keyword occurrence is depicted in Figure 9, where keywords depicted in yellow are emerging themes, and the one in blue are the foundational.

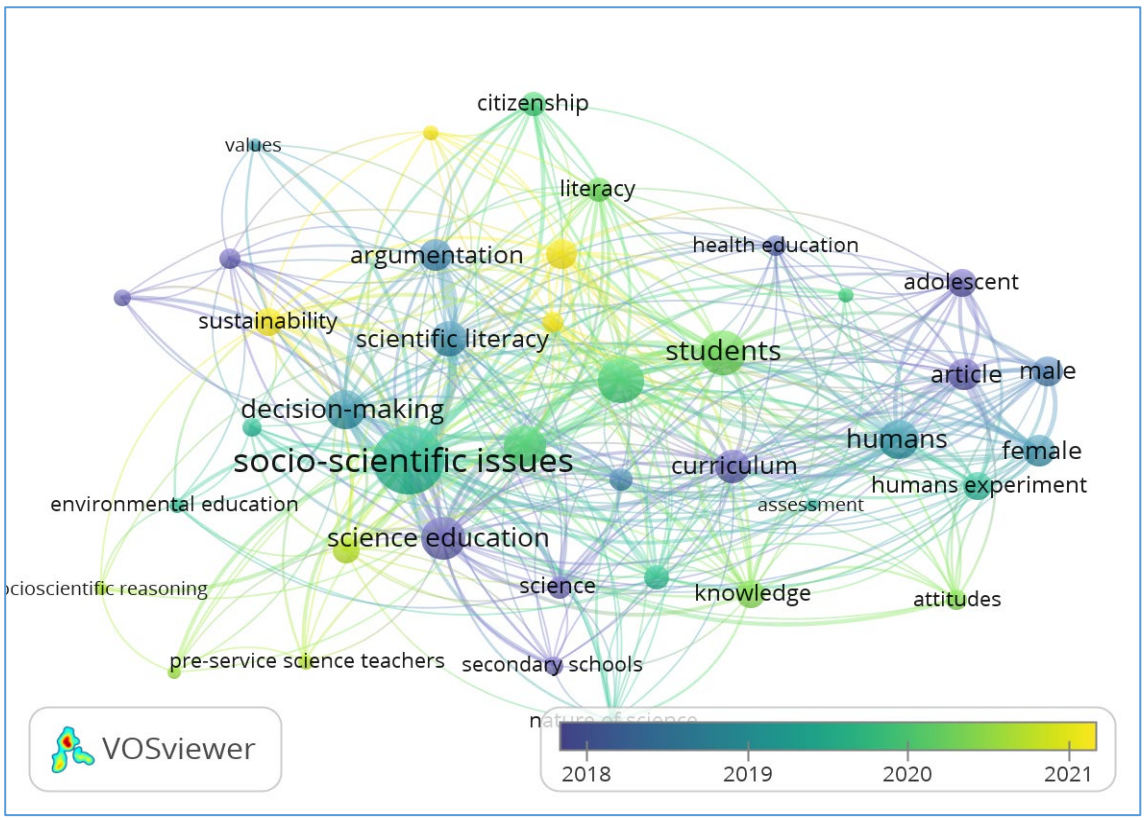

Figure 6: Overlay visualisation of keyword co-occurrence.

Author co-citation analysis

The analysis of co-citation, that is, the occurrence of two publications or authors being cited together in the same text, has long been recognized as a standard procedure in bibliometric analysis (Rossini, 2024). Co-citation analysis with authors and cited references was done to identify the crux of educational research focused on socio-scientific issues. A fractional counting method was opted in VOSviewer, instead of the full-counting method, since fractional counting produces a more accurate and balanced picture of the co-citation network, by reducing the influence of articles with exceptionally large reference lists. The minimum number of co-citations received by an author was set at 30, after having a thorough discussion among the investigators. With a total of 19,857 authors in the dataset, applying this cutoff resulted in a subset of 100 authors meeting the criterion, representing approximately 0.5% of the overall author population in the dataset. Visual representation (Figure 10) of the co-citation network reveals that the top 100 authors in the data set are distributed in six different clusters. The cluster sizes vary greatly, with 1 and 2 having the most authors, each with 23 (46% of the total authors in the analysis). Cluster 3 has 20 authors (20%), cluster 4 has 14 authors (14%), cluster 5 has 13 authors (13%), and cluster 6 has the fewest authors (7%).

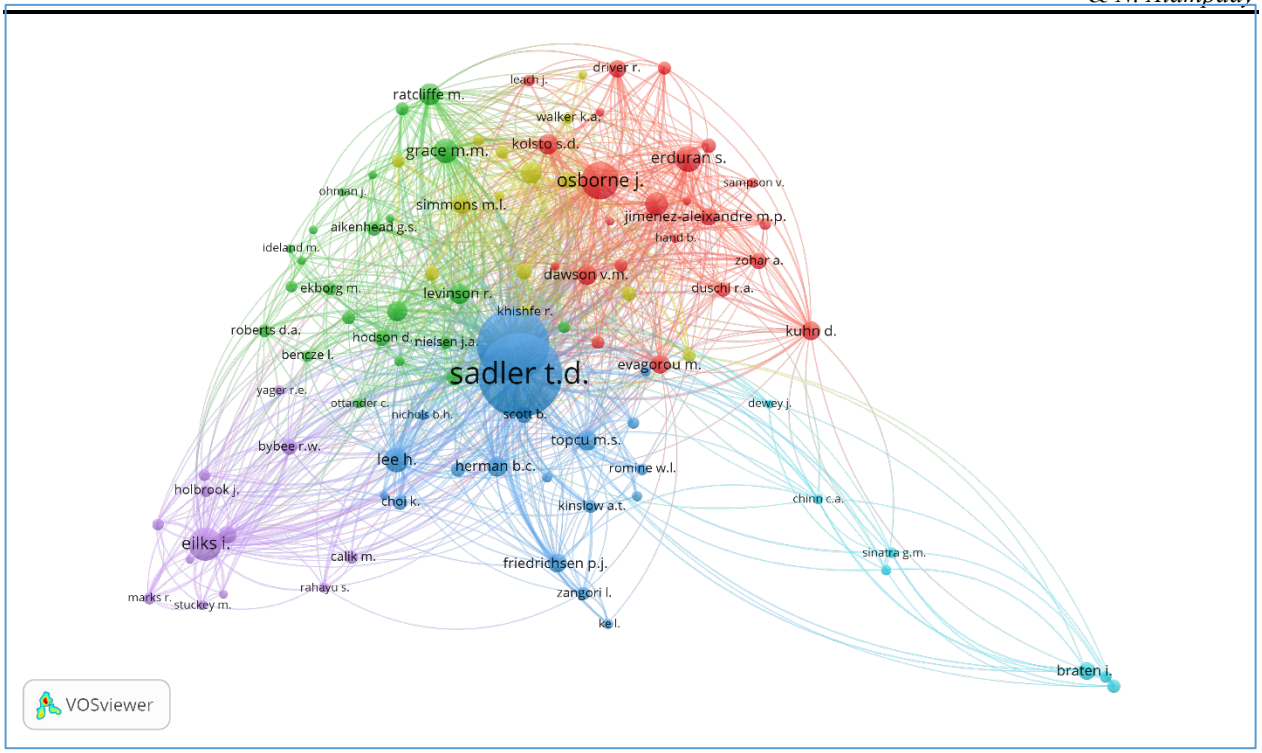

Figure 7: Network visualisation author co-citation analysis.

Cluster 1, depicted in red, consists of 23 items that contribute to a total of 1957 citations in the analysis. This cluster accounts for 21.77% of the total citations. Prominent authors within cluster 1 include Osborne J., with 335 citations, making up 17.12% of the cluster's citations. Other prominent authors are Erduran S. (178 citations) and Simon S. (151 citations). Similarly, cluster 2, represented by the green colour, also contains 23 items, contributing 1454 citations, which accounts for 16.17% of the total. Leading authors in this cluster are Grace M.M., with 164 citations, representing 11.28% of the cluster's citations, and Hodson D., who has 81 citations. Additional influential authors include Nielsen J.A. (59 citations).

Cluster 3, indicated in blue, emerges as the most influential and cited cluster, comprising 20 items, with 3440 citations, contributing 38.25% to the overall citation count. The dominant authors in this cluster are Sadler T.D., with a substantial 1272 citations, accounting for 36.98% of the cluster's total, and Zeidler D.L., with 967 citations (28.11% of the cluster). Other notable contributors include Lee H. (162 citations) and Scott B. (75 citations).

Apart from this, cluster 4, highlighted in the yellow colour, with 14 items, contributes 927 citations, making up 10.31% of the total. Lederman N.G. is the leading author in this cluster, with 130 citations, representing 14.02% of the total. Other significant authors include Simmons M.L. (105 citations) and Tsai C.C. (53 citations).

Furthermore, cluster 5, in purple, consists of 13 items and contributes 870 citations, which is 9.67% of the overall count. Eilks I. stands out, with 276 citations, accounting for 31.72% of the cluster's citations. Other key contributors are Hofstein A. (97 citations) and Sjostrom J. (51 citations). The high citation count for Eilks I. signifies a substantial impact within this relatively small cluster.

Additionally, cluster 6, in turquoise colour, the smallest with 7 items, contributes 343 citations, representing 3.81% of the total citations. Leading authors in this turquoise-tinted cluster include Stromso H.I. with 61 citations (17.78% of the cluster's total), Sinatra G.M. (39 citations), and Pekrun R. (35 citations).

Table 7: Cluster-wise analysis of author co-citation.

Cluster	Number of Items	Author 1	Citations 1	Author 2	Citations 2	Author 3	Citations 3
Cluster 1	23	Osborne J.	335	Erduran S.	178	Simon S.	151
Cluster 2	23	Grace M.M.	164	Hodson D.	81	Nielsen J.A.	59
Cluster 3	20	Sadler T.D.	1272	Zeidler D.L.	967	Lee H.	162
Cluster 4	14	Lederman N.G.	130	Simmons M.L.	105	Tsai C.C.	53
Cluster 5	13	Eilks I.	276	Hofstein A.	97	Sjostrom J.	51
Cluster 6	7	Stromso H.I.	61	Sinatra G.M.	39	Pekrun R.	35

In conclusion, cluster 3 defines the intellectual structure of the educational research domain that is focused on socio-scientific issues. The dominance of authors like Sadler T.D. (1272 citations, 36.98% of the cluster) and Zeidler D.L. (967 citations, 28.11% of the cluster) within this cluster highlights their influential contributions to the intellectual discourses on socio-scientific issues. Additionally, the highest citation count reveals that their research works have been the fulcrum of further studies, specifically the methodological and theoretical foundations that they laid. Even though cluster 3 has its foundational role and potential agenda-setting capabilities, interestingly, the presence of influential authors within smaller clusters (e.g., cluster 5 and cluster 6) suggests the existence of specialized or emerging research communities that contribute to the intellectual diversity of the research area (Rauchfleisch & Schäfer, 2018; Wei & Zhang, 2020).

Reference co-citation analysis

Co-citation, with reference, has been done to identify the intellectual trajectories of educational research domains focused on socio-scientific issues. The minimum number of citations received for a co-cited reference is 15, which is met by 19 references out of 17610. The co-cited references included in the analysis have distinct spans of years; Toulmin's "The Uses of Argument" from 1958 is the oldest, while “Next Generation Science Standards” from 2013 is the most recent. The citation counts show influence and significance among the selected references, ranging from 15 (the lowest criterion) to 75 (the highest). Several works authored by Sadler, either alone or alongside others, appear multiple times on the list. Among these are publications on the morality of socio-scientific issues (2004), socioscientific inquiry (2007), and informal reasoning processes in socioscientific decision-making (2005). These findings imply that Sadler's contributions to educational research focused on socio-scientific issues have had a significant impact, which, in turn, acts as the basis of the intellectual structure of this research area. These publications highlight the importance of reasoning skills and inquiry-based approaches when engaging with socio-scientific issues. Other frequently referenced authors include Zeidler, who has collaborated with Sadler and others on topics such as “socio-scientific issues education” (2005), beliefs in the nature of science and responses to socioscientific dilemmas (2002), and socioscientific issues in theory

and practice (2009). Apart from this, Driver, Newton, and Osborne's work on establishing the norms of scientific argumentation in classrooms (2000) also appears to be highly cited (42).

Table 8: Cluster-wise analysis of reference co-citation.

Sl.No	Cluster	Cited Reference	Citation	Link strength
1	3	Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, *41*(5), 513–536. https://doi.org/10.1002/tea.20009	75	64
2	4	Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education*, *37*(4), 371–391. https://doi.org/10.1007/S11165-006-9030-9/FIGURES/3	53	43
3	1	Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education,* 89(3). https://doi.org/10.1002/sce.20048	44	36
4	2	Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. https://doi.org/https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A	42	40
5	3	Ratcliffe, M. ., & Grace, M. (2005). Science education for citizenship : Teaching socio-scientific issues. *British Educational Research Journal*, *31*(6).	40	35
6	3	Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching*, *42*(1). https://doi.org/10.1002/tea.20042	30	27.67
7	2	Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, *39*(1), 35–62. https://doi.org/10.1002/tea.10008	28	26
8	3	Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1). https://doi.org/10.1080/03057260802681839	28	22

9	4	*National Science Education Standards*. (1996). National Academies Press. https://doi.org/10.17226/4962	27	24
10	1	Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, *86*(3), 343–367. https://doi.org/10.1002/sce.10025	25	21
11	3	Zeidler, D. L. (2009). Socioscientific issues: Theory and practice. *Journal of Elementary Science Education • Spring*, *21*(2), 49–58.	25	19
12	1	Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education*, *88*(1). https://doi.org/10.1002/sce.10101	24	23
13	1	Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education*, *85*(3). https://doi.org/10.1002/sce.1011	24	22
14	2	Toulmin, S. (1958). *The Uses of Argument* (Issue 130). Cambridge University Press.	24	21
15	4	*Next Generation Science Standards*. (2013). National Academies Press. https://doi.org/10.17226/18290	24	16
16	4	A framework for K-12 science education. (2012). In *A Framework for K-12 Science Education*. https://doi.org/10.17226/13165	23	18
17	2	Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10). https://doi.org/10.1002/tea.20035	17	16
18	2	Kuhn, D. (1991). The skills of argument. In *The skills of argument.* Cambridge University Press. https://doi.org/10.1017/CBO9780511571350	17	15
19	1	Sadler, T. D., & Donnelly, L. A. (2006). Socioscientific argumentation: The effects of content knowledge and morality. *International Journal of Science Education*, *28*(12), 1463–1488. https://doi.org/10.1080/09500690600708717	15	14

The strength of the co-citation relationships between the references is indicated by the total link strength values listed in the data. Higher-linkstrength references suggest that these works are closely co-cited with other influential publications in the field. Sadler (2004a), with a link strength of 64, and Sadler et al., (2007), with a link strength of 43, are such references. Figure 11 represents the network visualisation of reference co-citation analysis sorted by number of citations. The items cited frequently together are grouped; further association is defined by the similarity of the themes and ideas (Jan van Eck & Waltman, 2023). The largest cluster, which is cluster 1 (red), forms the theoretical foundations, encompassing conceptual frameworks, moral reasoning, scientific literacy, and the interplay between beliefs about the nature of science and socioscientific decision-making (Kolstø, 2001; Sadler & Zeidler, 2004; D. L. Zeidler et al., 2005). The highly cited work "Beyond STS: A Research-Based Framework for Socioscientific Issues Education" (D. L. Zeidler et al., 2005), with 44 citations and a link strength of 36, presents a research-based framework for this area of study, extending beyond the traditional science, technology, and society (STS) approach. Another influential paper in this cluster is "The Morality of Socioscientific Issues: Construal and Resolution of Genetic Engineering Dilemmas" (Sadler & Zeidler, 2004), which has 24 citations, a link strength of 23, and investigates the moral dimensions of socioscientific issues, specifically in the context genetic engineering dilemmas. Kolstø's (2001) work "Scientific Literacy for Citizenship: Tools for Dealing with the Science Dimension of Controversial Socioscientific Issues," with 22 citations and a link strength of 24, emphasizes the role of scientific literacy in equipping citizens to engage with the scientific aspects of controversial socioscientific issues.

Furthermore, the work "Tangled Up in Views: Beliefs in the Nature of Science and Responses to Socioscientific Dilemmas" (D. L. Zeidler et al., 2002), which has 25 citations and a link strength of 21, investigates the relationship between views about the nature of science and response to socio-scientific issues. Notably, "Socioscientific Argumentation: The Effects of Content Knowledge and Morality" (Sadler & Donnelly, 2006), which has 15 citations and a link strength of 14, investigates the effects of content knowledge and morality on socio-scientific argumentation, bridging the domain's cognitive and ethical dimensions. Conclusively, ideas or themes in this cluster are more aligned with theoretical foundations and conceptual bases of this topic.

The green cluster (cluster 2) seems to focus on the role of argumentation in science education and the development of argumentation skills. It has been denoted by the presence of reference articles like "Establishing the Norms of Scientific Argumentation in Classrooms" (Driver et al.,2000), "Fostering Students' Knowledge and Argumentation Skills through Dilemmas in Human Genetics" (Zohar & Nemet, 2002), "Enhancing the Quality of Argumentation in School Science" (Osborne et al., 2004), "The Skills of Argument"(Kuhn,1991) and Toulmin's (1958) work "The Uses of Argument." The citation count ranges from at least 17 to a maximum of 42, indicating that the role of these seminal works is crucial. In conclusion, the role of argumentation, discourse and reasoning in socio-scientific issues, particularly in classrooms and educational settings, is investigated by the cited references in this cluster, with a focus on how these concepts intersect with the scientific dimensions of diverse socio-scientific issues.

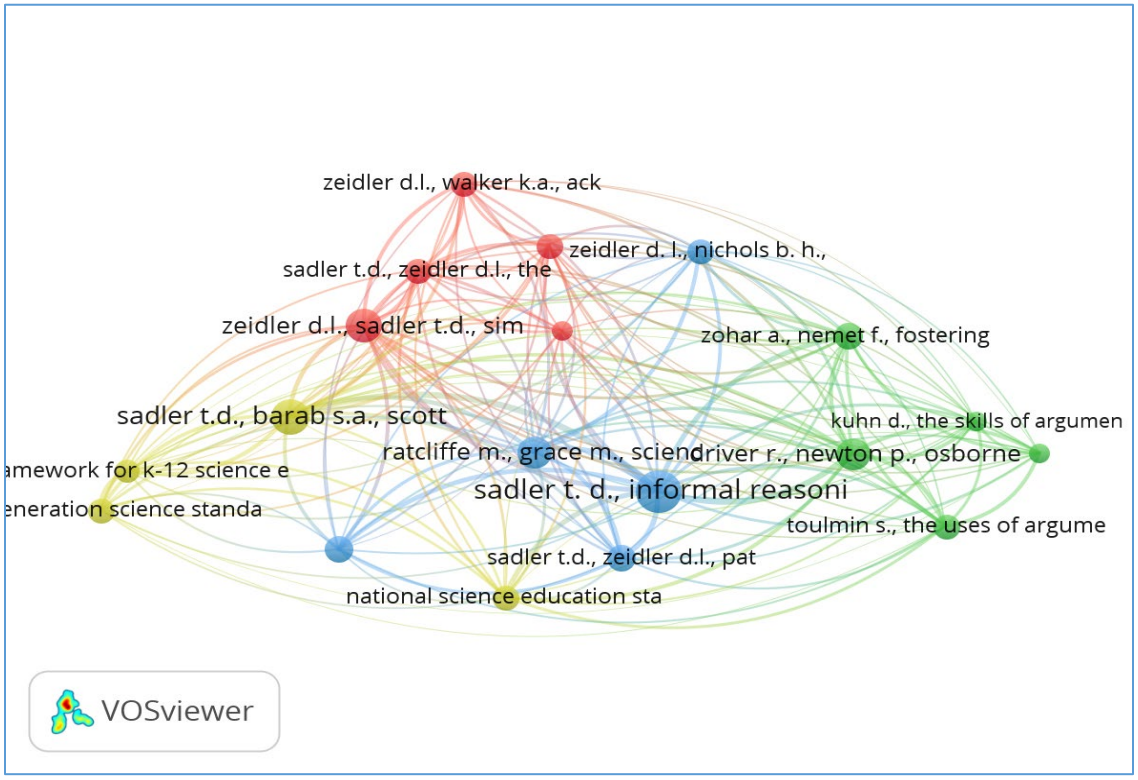

Figure 11: Network visualization of reference co-citation analysis.

Cluster 3, denoted in blue, is themed on the application of socio-scientific issues in teaching and learning contexts, with an emphasis on informal reasoning and situated learning approaches, as well as the role of socio-scientific issues in promoting citizenship education. The cluster consists of the highest cited work, "Informal Reasoning Regarding Socioscientific Issues: A Critical Review of Research" (Sadler, 2004a), with 75 citations and a link strength of 64, which forms the basis of the intellectual structure. Knowledge structure is further updated by the presence of scholarly works like, “Socioscientific Issues: Theory and Practice" (D. L. Zeidler, 2009), "Science Education for Citizenship: Teaching Socio-Scientific Issues” (Ratcliffe & Grace, 2005), “Situated Learning in Science Education: Socio-Scientific Issues as Contexts for Practice” (Sadler, 2009), and "Patterns of Informal Reasoning in the Context of Socioscientific Decision Making” (Sadler & Zeidler, 2005a).

Finally, cluster 4 (yellow) focuses on policy papers and frameworks that govern science-education practices, such as the National Science Education Standards, Next Generation Science Standards, and Framework for K-12 Science Education (“A Framework for K-12 Science Education,” 2012; *National Science Education Standards*, 1996; *Next Generation Science Standards*, 2013).

Discussion and Conclusion

This study revealed the prominent authors, influential documents, sources, and countries involved in educational research that is focused on socio-scientific issues. The trend is volatile in the number of documents and citations over the years. A significant spike in the amount of publications and citations is evident from 2019 to 2020, highlighting the growing recognition and importance of

this research area. The substantial increase in publications emphasizes the growing urgency of integrating SSI into educational frameworks, reflecting global priorities, such as critical thinking, sustainability, and responsible citizenship. The presence of a geographical concentration of research output, with contributions primarily from economically advanced nations, is evident. This disparity in global publications underlines the need for greater inclusivity and collaboration to ensure that voices from diverse regions, especially those directly impacted by socio-scientific issues, are incorporated. However, the absence of scholarly articles, during the period from 2003 to 2006, raises concerns about potential barriers to knowledge dissemination, such as economic elitism (zero open access publication in the area) and language restrictions (two articles were in languages other than English).

Furthermore, newer, high-impact journals emerged as critical platforms for disseminating SSI research, reflecting shifts in the dissemination of studies and demonstrating the need for open-access models to democratize participation.

Key themes, including climate change and sustainability, dominate the discourse, suggesting an alignment between educational research and global issues, at present. The dominance of qualitative methodologies demonstrates a clear preference for in-depth exploration of SSI, often involving case studies and contextual analysis. However, the presence of mixed-methods research design indicates a balancing of qualitative insights with quantitative generalizability. In essence, the findings show an evolving field that is increasingly concerned with addressing global educational challenges through a socio-scientific lens.

The findings of the study indicate that the growth of SSI educational research publications has increased over time. This notable increase is previously reported in the works that were reviewed (Li & Guo, 2021). Science educational journals acted as the primary source for disseminating SSI-related educational research, including the International Journal of Science Education and the Journal of Research in Science Teaching. This observation aligns with the studies of Ban & Mahmud (2023) and Li & Guo (2021). Apart from this, the journal Ensenanza De Las Ciencias, due to its multilingual coverage, signifies the global coverage of SSI-related research and is listed among the top 15 journals. Key themes widely discussed in educational research focused on SSI are climate change and sustainability, as observed by Schenk et al. (2021).The growing body of co-cited references centred on argumentation-related socio-scientific issues suggests that the studies in educational research which are focused on this subject are keen about analyzing the concept of "epistemic fluency," which can be defined as the adapting ability of students with different ways of understanding the world (Ben-Horin et al., 2023). Evidence fromprevious works(Chowdhury et al., 2020; López-Fernández et al., 2022) substantiates this argument.

Methodologically, this study's reliance on a single database and articles from English may skew the visibility of non-English and marginalize voices from underrepresented regions. This limitation could have influenced the study's thematic and geographic diversity. The gap identified regarding the absence of publications from 2003 to 2006, and issues such as economic elitism can be further developed as one of the criticisms; the researchers only considered "open access all" articles, which could have omitted potential articles in subscription-based journals. The decision to limit the analysis to journal articles further omitted contributions in formats, such as conference proceedings, book chapters, and review articles. Limitations related to the analytical software VOSviewer could also have influenced the findings. Future research could benefit from incorporating alternative tools, such as Biblioshiny, BibExcel, CiteSpace, or HistCite, to provide a better bibliometric analysis.

Education in the era of extensive technological integration is often evident as an application of technological dimensions in common constructs. Interestingly, technological integration-oriented research endeavours are less focused on educational research related to socio-scientific issues. Hence, upcoming efforts in this area can be focused on technological dimensions. The prevalence of particular nations and journals highlights the need for more extensive international cooperation and free access to knowledge, while also pointing to concentrated research resources. The varied approaches and new developments found by citation and keyword analysis demonstrate complex and dynamic intellectual environments. Maximizing the impact of educational research focused on SSI, educational practices, and policies worldwide requires addressing research contribution differences and promoting international cooperation.

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References

A framework for K-12 science education. (2012). In *A Framework for K-12 Science Education*. https://doi.org/10.17226/13165

Aghaei Chadegani, A., Salehi, H., Md Yunus, M. M., Farhadi, H., Fooladi, M., Farhadi, M., & Ale Ebrahim, N. (2013). A comparison between two main academic literature collections: Web of science and scopus databases. *Asian Social Science*, *9*(5). https://doi.org/10.5539/ass.v9n5p18

Badeo, J. M., & Duque, D. A. (2022). The effect of socio-scientific issues (SSI) in teaching science: A meta-analysis study. *Journal of Technology and Science Education*, *12*(2), 291. https://doi.org/10.3926/jotse.1340

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

Barab, S. A., Sadler, T. D., Heiselt, C., Hickey, D., & Zuiker, S. (2007). Relating narrative, inquiry, and inscriptions: Supporting consequential play. *Journal of Science Education and Technology*, *16*(1), 59–82. https://doi.org/10.1007/s10956-006-9033-3

Barzilai, S., & Chinn, C. A. (2020). A review of educational responses to the "post-truth" condition: Four lenses on "post-truth" problems. *Educational Psychologist*, *55*(3), 107–119. https://doi.org/10.1080/00461520.2020.1786388

Bayer, A. E., Smart, J. C., & McLaughlin, G. W. (1990). Mapping intellectual structure of a scientific subfield through author cocitations. *Journal of the American Society for Information Science*, *41*(6), 444–452. https://doi.org/https://doi.org/10.1002/(SICI)1097-4571(199009)41:6<444::AID-ASI12>3.0.CO;2-J

Ben-Horin, H., Kali, Y., & Tal, T. (2023). The fifth dimension in socio-scientific reasoning: Promoting decision-making about socio-scientific issues in a community. *Sustainability (Switzerland)*, *15*(12). https://doi.org/10.3390/su15129708

Cavagnetto, A. R. (2010). Argument to foster scientific literacy: A review of argument interventions in K-12 science contexts. *Review of Educational Research*, *80*(3), 336–371. https://doi.org/10.3102/0034654310376953

Chowdhury, T. B. M., 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

Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). Science mapping software tools: Review, analysis, and cooperative study among tools. *Journal of the American Society for Information Science and Technology*, *62*(7). https://doi.org/10.1002/asi.21525

Dawson, V. M., & Venville, G. (2010). Teaching strategies for developing students' argumentation skills about socioscientific issues in high school genetics. *Research in Science Education*, *40*(2), 133–148. https://doi.org/10.1007/s11165-008-9104-y

Dede, E., & Ozdemir, E. (2022). Mapping and performance evaluation of mathematics education research in Turkey: A bibliometric analysis from 2005 to 2021. *Journal of Pedagogical Research*, *6*(4). https://doi.org/10.33902/JPR.202216829

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. https://doi.org/https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Ebrahim, N. A., Salehi, H., Embi, M. A., Tanha, F. H., Gholizadeh, H., Motahar, S. M., & Ordi, A. (2013). Effective strategies for increasing citation frequency. *International Education Studies*, *6*(11), p93. https://doi.org/10.5539/IES.V6N11P93

Eilks, I. (2015). Science education and education for sustainable development - justifications, models, practices and perspectives. *Eurasia Journal of Mathematics, Science and Technology Education*, *11*(1), 149–158. https://doi.org/10.12973/eurasia.2015.1313a

Evagorou, M., Jimenez-Aleixandre, M. P., & Osborne, J. (2012). "Should we kill the grey squirrels?" A study exploring students' justifications and decision-making. *International Journal of Science Education*, *34*(3), 401–428. https://doi.org/10.1080/09500693.2011.619211

Evren-Yapicioglu, A. (2018). Advantages and Disadvantages of Socioscientific Issue-Based Instruction in Science Classrooms. *International Online Journal of Education and Teaching*, *5*(2), 361–374.

Furberg, A., & Ludvigsen, S. (2008). Students' meaning-making of socioscientific issues in computer mediated settings: Exploring learning through interaction trajectories. *International Journal of Science Education*, *30*(13), 1775–1799. https://doi.org/10.1080/09500690701543617

Grace, M. (2009). Developing high quality decision-making discussions about biological conservation in a normal classroom setting. *International Journal of Science Education*, *31*(4), 551–570. https://doi.org/10.1080/09500690701744595

Gunasekaran, D., Kumar, A. G., & A., N. (2022). Multicultural education in India: A historical exploration. *The International Journal of Interdisciplinary Cultural Studies*, *17*(2), 75–82. https://doi.org/10.18848/2327-008X/CGP/v17i02/75-82

Haddow, G., & Genoni, P. (2010). Citation analysis and peer ranking of Australian social science journals. *Scientometrics*, *85*(2). https://doi.org/10.1007/s11192-010-0198-4

Hancock, T. S., Friedrichsen, P. J., Kinslow, A. T., & Sadler, T. D. (2019). Selecting socio-scientific issues for teaching: A grounded theory study of how science teachers collaboratively design SSI-based curricula. *Science and Education*, *28*(6–7), 639–667. https://doi.org/10.1007/s11191-019-00065-x

Hingant, B., & Albe, V. (2010). Nanosciences and nanotechnologies learning and teaching in secondary education: A review of literature. *Studies in Science Education*, *46*(2), 121–152. https://doi.org/10.1080/03057267.2010.504543

Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(46). https://doi.org/10.1073/pnas.0507655102

Hota, P. K., Subramanian, B., & Narayanamurthy, G. (2020). Mapping the intellectual structure of social entrepreneurship research: A citation/co-citation analysis. *Journal of Business Ethics*, *166*(1). https://doi.org/10.1007/s10551-019-04129-4

Ignatow, G., & Robinson, L. (2017). Pierre Bourdieu: Theorizing the digital. *Information Communication and Society*, *20*(7). https://doi.org/10.1080/1369118X.2017.1301519

Iordanou, K., & Constantinou, C. P. (2014). Developing pre-service teachers' evidence-based argumentation skills on socio-scientific issues. *Learning and Instruction*, *34*, 42–57. https://doi.org/10.1016/j.learninstruc.2014.07.004

Jan van Eck, N., & Waltman, L. (2023). *VOSviewer Manual*.

José de Oliveira, O., Francisco da Silva, F., Juliani, F., César Ferreira Motta Barbosa, L., & Vieira Nunhes, T. (2019). Bibliometric method for mapping the state-of-the-art and Identifying Research Gaps and Trends in Literature: An Essential Instrument to Support the development of scientific projects. In *Scientometrics Recent Advances*. https://doi.org/10.5772/intechopen.85856

Jukola, P. (2007). Education+: Creativity and multidisciplinary skills. *International Astronautical Federation - 58th International Astronautical Congress 2007*, *12*.

Kahn, S., & Zeidler, D. L. (2019). A conceptual analysis of perspective taking in support of socioscientific reasoning. *Science and Education*, *28*(6–7), 605–638. https://doi.org/10.1007/s11191-019-00044-2

Kavitha, K., & Joshith, V. P. (2024). The transformative trajectory of artificial intelligence in education: The two decades of bibliometric retrospect. *Journal of Educational Technology Systems*, *52*(3), 376–405. https://doi.org/10.1177/00472395241231815

Ke, L., Sadler, T. D., Zangori, L., & Friedrichsen, P. J. (2021). Developing and using multiple models to promote scientific literacy in the context of socio-scientific issues. *Science and Education*, *30*(3), 589–607. https://doi.org/10.1007/s11191-021-00206-1

Khotinets, V. Yu., & Shishova, E. O. (2023). Cultural and educational environment in the development of younger schoolchildren's creative potential. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1178535

Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education*, *85*(3). https://doi.org/10.1002/sce.1011

Kuhn, D. (1991). The skills of argument. In *The skills of argument.* Cambridge University Press. https://doi.org/10.1017/CBO9780511571350

Kumar, V., Choudhary, S. K., & Singh, R. (2024). Environmental socio-scientific issues as contexts in developing scientific literacy in science education: A systematic literature review. *Social Sciences & Humanities Open*, *9*, 100765. https://doi.org/10.1016/j.ssaho.2023.100765

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal*, *32*(3), 465. https://doi.org/10.2307/1163320

Li, Y., & Guo, M. (2021). Scientific literacy in communicating science and socio-scientific issues: Prospects and challenges. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.758000

Lim, W. M., Kumar, S., & Donthu, N. (2024). How to combine and clean bibliometric data and use bibliometric tools synergistically: Guidelines using metaverse research. *Journal of Business Research*, *182*, 114760. https://doi.org/10.1016/j.jbusres.2024.114760

López-Fernández, M. D. M., González-García, F., & Franco-Mariscal, A. J. (2022). How can socio-scientific issues help develop critical thinking in chemistry education? A reflection on the problem of plastics. *Journal of Chemical Education*, *99*(10), 3435–3442. https://doi.org/10.1021/acs.jchemed.2c00223

Mariotti, C. (2022). Elite theory. In A. & F. C. S. & B. A. S. Harris Phil & Bitonti (Eds.), *The Palgrave encyclopedia of interest groups, lobbying and public affairs* (pp. 427–432). Springer International Publishing. https://doi.org/10.1007/978-3-030-44556-0_67

Meisner, R., vom Lehn, D., Heath, C., Burch, A., Gammon, B., & Reisman, M. (2007). Exhibiting performance: Co-participation in science centres and museums. *International Journal of Science Education*, *29*(12), 1531–1555. https://doi.org/10.1080/09500690701494050

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2010). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *International Journal of Surgery*, *8*(5), 336–341. https://doi.org/10.1016/J.IJSU.2010.02.007

Molinatti, G., Girault, Y., & Hammond, C. (2010). High school students debate the use of embryonic stem cells: The influence of context on decision-making. *International Journal of Science Education*, *32*(16), 2235–2251. https://doi.org/10.1080/09500691003622612

Mongeon, P., Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics*, *106*, 213–228. https://doi.org/10.1007/s11192-015-1765-5

National Science Education Standards. (1996). National Academies Press. https://doi.org/10.17226/4962

Next Generation Science Standards. (2013). National Academies Press. https://doi.org/10.17226/18290

Nissani, M. (1997). Ten cheers for interdisciplinarity: The case for interdisciplinary knowledge and research. *Social Science Journal*, *34*(2). https://doi.org/10.1016/S0362-3319(97)90051-3

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

Özcan, E., & Balım, A. G. (2021). The effect of socio-scientific argumentation method on students' entrepreneurship perceptions. *Participatory Educational Research*, *8*(1), 309–321. https://doi.org/10.17275/per.21.18.8.1

Piaget, J. (1964). Part I: Cognitive development in children: Piaget development and learning. *Journal of Research in Science Teaching*, *2*(3). https://doi.org/10.1002/tea.3660020306

Ratcliffe, M., & Grace, M. (2005). Science education for citizenship : Teaching socio-scientific issues. *British Educational Research Journal*, *31*(6).

Rauchfleisch, A., & Schäfer, M. S. (2018). Structure and development of science communication research: Co-citation analysis of a developing field. *Journal of Science Communication*, *17*(3). https://doi.org/10.22323/2.17030207

Rossini, P. (2024). Networks as interpretative frameworks: Using co-citation analysis to explore large corpora of early modern letters. *Digital Scholarship in the Humanities*, *39*(1). https://doi.org/10.1093/llc/fqad086

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

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1). https://doi.org/10.1080/03057260802681839

Sadler, T. D. (2011a). *Situating socio-scientific issues in classrooms as a means of achieving goals of science education*. 1–9. https://doi.org/10.1007/978-94-007-1159-4_1

Sadler, T. D. (2011b). *Socio-scientific issues-based education: What we know about science education in the context of SSI*. https://doi.org/10.1007/978-94-007-1159-4_20

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education*, *37*(4), 371–391. https://doi.org/10.1007/S11165-006-9030-9/FIGURES/3

Sadler, T. D., & Donnelly, L. A. (2006). Socioscientific argumentation: The effects of content knowledge and morality. *International Journal of Science Education*, *28*(12), 1463–1488. https://doi.org/10.1080/09500690600708717

Sadler, T. D., & Zeidler, D. L. (2004). The morality of socioscientific issues: Construal and resolution of genetic engineering dilemmas. *Science Education*, *88*(1). https://doi.org/10.1002/sce.10101

Sadler, T. D., & Zeidler, D. L. (2005a). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching*, *42*(1). https://doi.org/10.1002/tea.20042

Sadler, T. D., & Zeidler, D. L. (2005b). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education*, *89*(1), 71–93. https://doi.org/10.1002/SCE.20023

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

Simonneaux, L., & Simonneaux, J. (2009). Students' socio-scientific reasoning on controversies from the viewpoint of education for sustainable development. *Cultural Studies of Science Education*, *4*(3), 657–687. https://doi.org/10.1007/s11422-008-9141-x

Sjöström, J., Frerichs, N., Zuin, V. G., & Eilks, I. (2017). Use of the concept of Bildung in the international science education literature, its potential, and implications for teaching and learning. *Studies in Science Education*, *53*(2), 165–192. https://doi.org/10.1080/03057267.2017.1384649

Tahamtan, I., Safipour Afshar, A. & Ahamdzadeh, K. (2016). Factors affecting number of citations: A comprehensive review of the literature. *Scientometrics*, *107*, 1195–1225. https://doi.org/10.1007/s11192-016-1889-2

Tang, K.-Y., Lin, T.-C., & Hsu, Y.-S. (2024). Status and trends of socioscientific issues in educational literature: Insights and extensions from a co-word analysis. *International Journal of Science Education*, *46*(11), 1073–1097. https://doi.org/10.1080/09500693.2023.2272603

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

Tomas, L., Rigano, D., & Ritchie, S. M. (2016). Students' regulation of their emotions in a science classroom. *Wiley Periodicals, Inc. J Res Sci Teach*, *53*(2), 234–260. https://doi.org/10.1002/tea.21304

Tomaszewski, R. (2023). Visibility, impact, and applications of bibliometric software tools through citation analysis. *Scientometrics*, *128*(7), 4007–4028. https://doi.org/10.1007/s11192-023-04725-2

Toulmin, S. (1958). *The uses of argument* (Issue 130). Cambridge University Press.

Van Raan, A. (2003). The use of bibliometric analysis in research performance assessment and monitoring of interdisciplinary scientific developments. *TATuP - Zeitschrift Für Technikfolgenabschätzung in Theorie Und Praxis*, *12*(1). https://doi.org/10.14512/tatup.12.1.20

Wei, F., & Zhang, G. (2020). A document co-citation analysis method for investigating emerging trends and new developments: A case of twenty-four leading business journals. *Information Research*, *25*(1).

Wheeler, J., Pham, N. M., Arlitsch, K., & Shanks, J. D. (2022). Impact factions: Assessing the citation impact of different types of open access repositories. *Scientometrics*, *127*(8). https://doi.org/10.1007/s11192-022-04467-7

Wirzal, M. D. H., Nordin, N. A. H. M., Bustam, M. A., & Joselevich, M. (2022). Bibliometric analysis of research on scientific literacy between 2018 and 2022: Science education subject. *International Journal of Essential Competencies in Education*, *1*(2), 69–83. https://doi.org/10.36312/ijece.v1i2.1070

Yang, J., & Liu, Z. (2022). The effect of citation behaviour on knowledge diffusion and intellectual structure. *Journal of Informetrics*, *16*(1). https://doi.org/10.1016/j.joi.2021.101225

Zakaria, R., Ahmi, A., Ahmad, A. H., & Othman, Z. (2021). Worldwide melatonin research: A bibliometric analysis of the published literature between 2015 and 2019. *Chronobiology International*, *38*(1), 27–37. https://doi.org/10.1080/07420528.2020.1838534

Zangori, L., Peel, A., Kinslow, A., Friedrichsen, P., & Sadler, T. D. (2017). Student development of model-based reasoning about carbon cycling and climate change in a socio-scientific

issues unit. *Journal of Research in Science Teaching*, *54*(10), 1249–1273. https://doi.org/10.1002/tea.21404

Zeidler, D. (2015). Socioscientific issues. *Encyclopedia of Science Education*, 998–1003. https://doi.org/10.1007/978-94-007-2150-0_314

Zeidler, D. L. (2009). Socioscientific issues: Theory and practice. *Journal of Elementary Science Education, 21*(2), 49–58.

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

Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, *89*(3), 357–377. https://doi.org/10.1002/sce.20048

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, *86*(3), 343–367. https://doi.org/10.1002/sce.10025

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, *39*(1), 35–62. https://doi.org/10.1002/tea.10008

Zupic, I., & Čater, T. (2014). Bibliometric methods in management and organization. *Https://Doi.Org/10.1177/1094428114562629*, *18*(3), 429–472. https://doi.org/10.1177/1094428114562629