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Research and Trends of Socio-Scientific Issues in Natural Science Education: Bibliometric and Content Analysis Based on Systematic Literature Review

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A B S T R ACT

The implementation of Socio-Scientific Issues (SSI)-based learning has been widely carried out in developed countries that have received international attention in the field of science education. This study uses a mixed-method approach. The quantitative approach employs bibliometric analysis data, while the qualitative approach uses content analysis data based on a systematic literature review. The design used is a triangulation design with a one-phase model. The research data source uses the Scopus database from 2004–2023 with the search keywords "Socio-Scientific and Issue" and "Science Education." The bibliometric data collection technique consists of three stages, namely defining the objective, selecting the sample, and statistical analysis. Meanwhile, the content analysis data collection technique uses the PRISMA model. The bibliometric results obtained 208 articles and were analyzed based on published SSI in Natural Science Education documents and authors, contribution of countries and affiliations, documents by subject area and co-occurrence network of the keywords, source articles of SSI, and citations. The content analysis results obtained 17 article studies included in the review with analysis based on study objective, methodology, main finding, and summary of discussion. Based on the results, it shows that the trend of SSI research from 2004–2023 has significantly increased with the highest research contribution from the United States. The most frequently studied influence of SSI in science education is scientific literacy skills, argumentation, reasoning, and problem-solving. The most frequently studied SSI topics are global warming and climate change. SSI-based learning strongly supports the implementation in science education, but teachers will face challenges in handling SSI because controversial issues will make it difficult to integrate with science content.

1. INTRODUCTION

Socio-scientific issues (SSI) focus on controversial problems that involve social aspects of society yet are closely related to science. Such issues require scientific understanding but also demand consideration of various factors such as ethics, culture, economics, politics, morality, and the environment (Kumar et al., 2024). SSI problems often lack definite answers; therefore, decision-making must take into account multiple aspects of both scientific knowledge and social contexts (Türk & Çam, 2024). In the educational sphere, however, the integration and development of contextual materials aligned with real and relevant social issues are essential to provide students with a deeper and more meaningful understanding (Abrori et al., 2024). This aligns with the view that science education must interconnect scientific knowledge with social realities, as emphasized in philosophical inquiries into modern educational science (Firdaus, 2025).

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SSI-based science education has been studied in many countries over the past two decades (Türk & Çam, 2024). The implementation of SSI-based learning is widely carried out in developed nations that have received international recognition for their attention to science education (Genisa et al., 2020). SSI can serve as a focal point in science learning by encouraging students to make decisions and express opinions on environmental issues (Yanti et al., 2024). Therefore, SSI-based instruction in science education encompasses several 21st-century skills related to solving problems occurring in the surrounding environment including self-regulation skills and critical thinking disposition, both of which are essential for making decisions on complex issues (Firdaus et al., 2025a).

The term Socio-scientific Issue (SSI) was first introduced by Fleming in 1984, who examined adolescents' reasoning freedom in making decisions related to socio-scientific issues (Fleming, 1986a). Fleming continued his research in 1986, discussing adolescents' reasoning within SSI, divided into two parts: Part I on Social Cognition and Part II on Non-Social Cognition. Both of these studies emphasized science education curricula focused on socio-scientific issues (Fleming, 1986a, 1986b).

The concept of SSI was further developed by Ratcliffe (1997), who explored students' decision-making concerning SSI within the science curriculum. According to Ratcliffe (1997), several key elements are essential in students' decision-making, such as procedural understanding of how to evaluate alternative solutions systematically by considering their strengths and weaknesses. Awareness and the use of relevant information serve as benchmarks in making decisions. Students are also encouraged to identify criteria before discussing issues to be more aware of arguments supporting specific options, as well as to utilize scientific evidence to strengthen their reasoning in the decision-making process.

Patronis and Spiliotopoulou (1999) investigated students' argumentation processes in making decisions on SSI. Their analysis revealed new dimensions of classroom argumentation, highlighting its diversity and dynamic nature. In recent years, six researchers have conducted studies on trends in socio-scientific issues.

Research on trends in socio-scientific issues published in Scopus over the past 20 years was first carried out by Pitiporntapin and Janta (2016), who studied trends of theses about socio-scientific issue-based teaching in Thailand using national thesis databases. In the same year, Tekin et al. (2016) conducted a content analysis on trends in socio-scientific issues based on selected publications from science education journals, though their study only used five specific journal sources. Meanwhile, Deta et al. (2021) analyzed trends of socio-scientific issues in physics education using bibliometric analysis from 2011 to 2020, focusing on Indonesian contributors within the Scopus database.

Research on SSI trends expanded rapidly in 2023, as more scholars began advocating for the application of socio-scientific issues in education, necessitating trend analyses to better understand their development. Ban and Mahmud (2023) conducted a study on trends in socio-scientific issue education through content analysis of journal publications from 2004 to 2022 using the Web of Science database. Similarly, Rery and Rahmasari (2023) carried out a literature review on trends of socio-scientific issues focused specifically on chemical kinetics materials from SINTA-accredited and Scopus-indexed journals, limiting their research scope to opportunities within Indonesia. Tang et al. (2023), on the other hand, explored the status and trends of socio-scientific issues in language education using insight and co-word analysis with data from both the Web of Science and Scopus databases.

All previous studies on trends in socio-scientific issues have not focused on natural science education. Therefore, this study offers a novel contribution to the global research community by presenting an updated overview of SSI research trends within science education. Additionally, while previous studies employed a single analytical approach, this research integrates both quantitative and qualitative analyses to produce more comprehensive and accurate insights. The dual-analytical approach provides researchers with a visual and conceptual understanding of current developments in SSI, allowing for better representation

of the discussed topics, this dual approach is also commonly employed in bibliometric analyses and conceptual reviews applied to research on instructional models such as 4MAT (Firdaus et al., 2025b).

An important aspect of SSI-based learning is its ability to make scientific concepts related to social issues more contextual when taught in the classroom (Yanti et al., 2024). However, the characteristics of SSI problems vary across countries depending on their socio-political and environmental conditions. Ecological issues tend to be among the most popular, as environmental challenges have become not only national concerns but also global ones (Genisa et al., 2020). Researchers worldwide have examined SSI to analyze its impacts, highlighting the need for a comprehensive understanding of SSI research trends in science education. Such understanding can serve as a valuable reference and guide for future researchers to enhance the quality and direction of SSI-related studies.

A science education curriculum focused on SSI requires knowledge that bridges real-world phenomena and social realities, encouraging students to integrate both domains (Fleming, 1986b). Furthermore, SSI-based science instruction promotes scientific literacy through various learning models that equip students with both knowledge and skills. However, instructional modeling within the SSI context has not yet been systematically investigated (Ke et al., 2021). In recent years, global research on SSI has shown significant changes in both content and volume of publications (Ban & Mahmud, 2023).

The purpose of this study is to provide deeper insights and understanding regarding SSI research trends in science education, encompassing both fundamental and content-based information. This article is expected to assist researchers in identifying relevant SSI studies within science education. Moreover, this review aims to identify prevailing SSI research trends from previous studies to uncover research gaps and facilitate the advancement of more robust SSI-related research in science education.

Research Question

a. How has international research on socio-scientific issues within science education been published over the past twenty years?
b. How can the content of research on socio-scientific issues in science education be analyzed?
c. What socio-scientific issue components have been addressed thus far in education research?
d. Which capacity-building dimensions have been most emphasized in the implementation of socio-scientific issues?
e. What are the global trends in research on socio-scientific issues in science education?

2. METHOD

This study employs a mixed-method approach that integrates both quantitative and qualitative analyses to examine the literature on research and trends of socio-scientific issues in natural science education over the past twenty years, from 2004 to 2023. The quantitative approach utilizes bibliometric analysis data, while the qualitative approach employs content analysis based on a systematic literature review. The research design used is a triangulation design with a one-phased model.

2.1 Bibliometric Analysis

Bibliometric analysis is a quantitative technique used to statistically analyze articles and measure their impact (Goyal et al., 2021). It is a statistical approach that provides accuracy in exploring and analyzing large volumes of scientific data to reveal variations and highlight developments within a particular field (Donthu et al., 2021). The bibliometric analysis in this study consists of three stages: defining the objective, selecting the sample, and conducting statistical analysis.

2.1.1 Defining the Objective

The purpose of applying bibliometric analysis in this study is to quantitatively and visually explore the research and trends of socio-scientific issues in natural science education using bibliometric statistical tools. Several quantitative characteristics of publications include the number of articles obtained, citation frequency, keyword frequency, subject categories, contributing countries, and source references. According to He et al. (2020), the number of publications and citation frequency can indicate changes in scientific attention toward specific research topics over time. Keyword frequency represents the main themes of the research, while subject categories and contributing countries illustrate the extent of the research's application across disciplines and regions. The source references, on the other hand, refer to the distribution of related studies across journals, books, and theses.

2.1.2 Selecting the Sample

This study uses articles sourced from the Scopus database over the past twenty years (2004–2023). Scopus was chosen because it is the largest international academic database, providing abstracts and citation information for peer-reviewed scientific literature (Tupan et al., 2018). The sample search was conducted by targeting the article title, abstract, and keywords using the terms "Socio-Scientific and Issue" and "Science Education."

2.1.3 Statistical Analysis

This study employs the VOSviewer (Visualization of Similarities) software to perform bibliometric analysis. The software requires Java to run. VOSviewer is a freely accessible tool designed to visualize and explore bibliometric knowledge maps (Leydesdorff & Rafols, 2012). Its integrated text-mining and clustering approach enables the identification of connections within bibliometric data, offering interactive visualization features that make data networks easy to explore and interpret (van Eck & Waltman, 2010). The clustering algorithm operates with adjustable parameters, and the density and color of clusters can also be displayed in VOSviewer (Leydesdorff & Rafols, 2012).

2.2 Content Analysis

The content analysis in this study adopts a Systematic Literature Review (SLR) approach to identify research and trends in socio-scientific issues within science education. The SLR method was chosen because it allows for mapping, assessing, and synthesizing literature to advance knowledge within a specific field (Tranfield et al., 2003). This method enables researchers to identify research gaps and generate new insights (Munaro et al., 2020).

The SLR method minimizes bias by systematically synthesizing scientific evidence to answer research questions through literature identification, collection, and processing. The SLR process can follow the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which provide an evidence-based framework for reporting systematic reviews (Page et al., 2021). The PRISMA procedure includes the stages of identification, screening, eligibility, and inclusion (Şalvarlı & Griffiths, 2021).

The literature analyzed in this study was systematically reviewed following the PRISMA reporting framework, consisting of three stages based on the identification of studies through databases and registers.

2.2.1 Identification

The identification stage involved selecting research relevant to the topic using two initial keyword combinations: "Socio-Scientific and Issue" and "Science Education." This process aimed to analyze trends in articles related to SSI in science education. The selected articles were exclusively sourced from the Scopus database, chosen for its status as the world's largest academic database (Tupan et al., 2018).

2.2.2 Screening

Screening was carried out in three stages to determine which articles would be analyzed. The first stage involved filtering by document type (articles), subject area (social sciences), source type (journals), and keywords (socio-scientific issues and science education). The second stage considered articles with a minimum of five citations. The final screening stage evaluated the relevance of each article to SSI research trends in science education.

2.2.3 Included

Articles that passed the inclusion stage were deemed eligible for analysis. The inclusion criteria were based on descriptive characteristics, including (i) the relevance of the article to the research topic and (ii) inclusivity, ensuring that the study could be meaningfully interpreted. The included articles were then analyzed based on their content to extract and synthesize insights aligned with the study objectives.

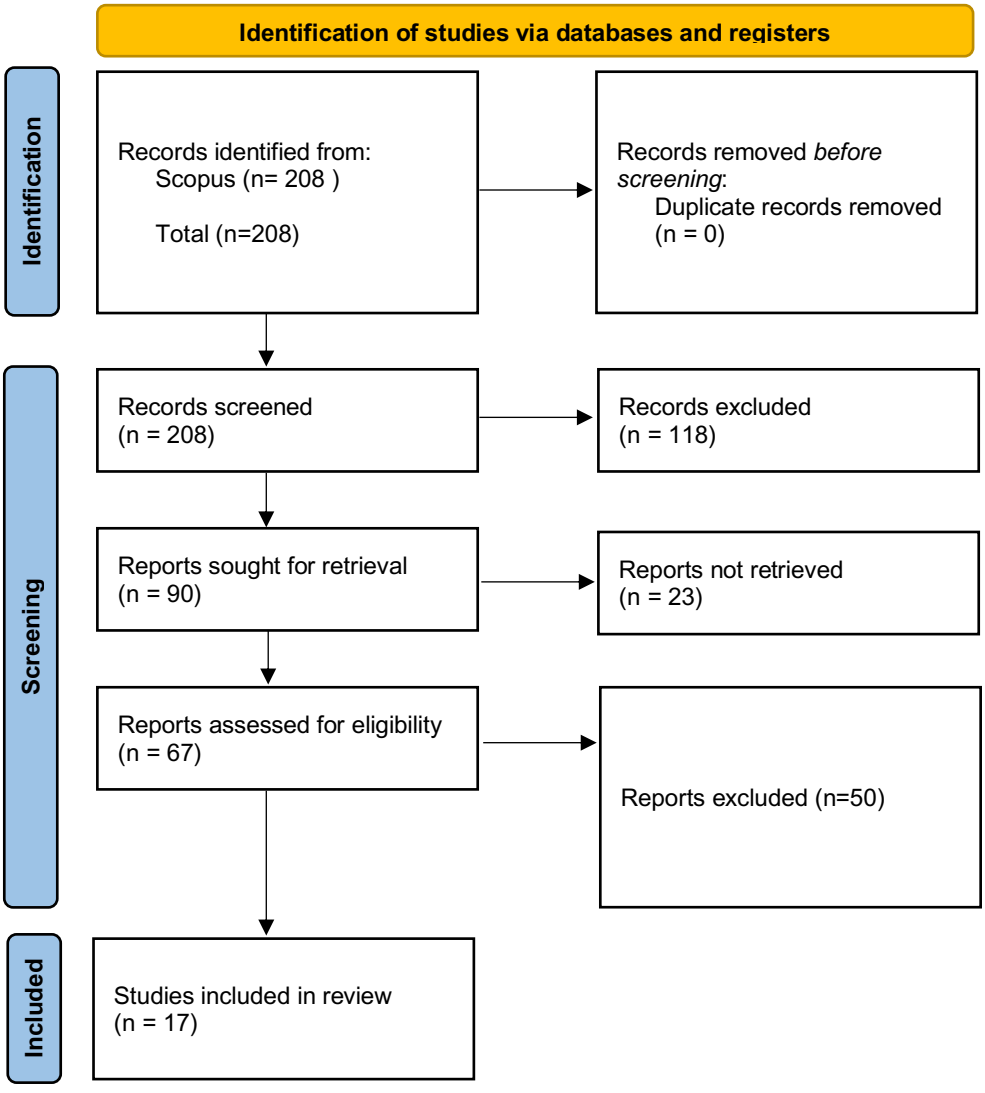

Figure 1. PRISMA Framework Design

3. RESULT AND DISCUSSION

3.1 Bibliometric Analysis

3.1.1 Published SSI in Natural Science Education Document and Authors

Based on the research findings, a total of 208 documents related to socio-scientific issues in science education were obtained from the Scopus database over the past twenty years. The development of SSI-related studies from 2004 to 2023 shows a continuous increase in the number of articles published in Scopus. The trend in the growth of these publications can be seen in Figure 2.

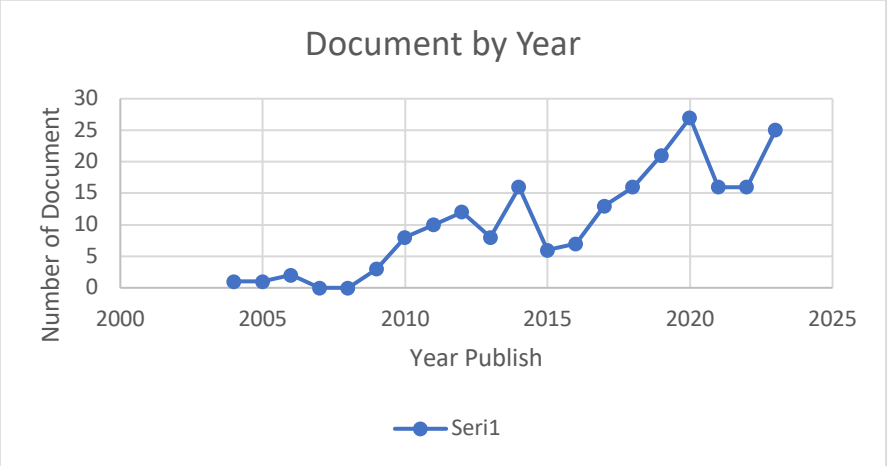

Figure 2. Development of SSI Publications Over the Last 20 Years

SSI research received relatively little attention between 2004 and 2009, as indicated by the small number of articles published in Scopus, which ranged from only one to three publications per year. In fact, during 2007 and 2008, there were no SSI-related articles published at all. However, in 2010, research on SSI began to gain momentum, and by 2014, there were 16 publications in Scopus focusing on SSI in science education. Nevertheless, a decline occurred the following year—specifically in 2015—with only six published articles.

The initial phase of SSI research exploration in science education took place between 2016 and 2020, showing a rapid increase and emerging as a topic of growing global interest. Research conducted in 2020 was heavily influenced by the COVID-19 pandemic, which shifted educational paradigms toward online learning, emphasizing environmentally based instruction and the incorporation of local environmental issues. Although SSI research trends declined again in 2021 and 2022 in terms of publication volume, the topic regained international attention in 2023.

Therefore, up to the present, SSI research in science education remains a persistent global trend and continues to be an active area of interest among international scholars. The mapping of SSI researchers in science education can be seen in Figure 3.

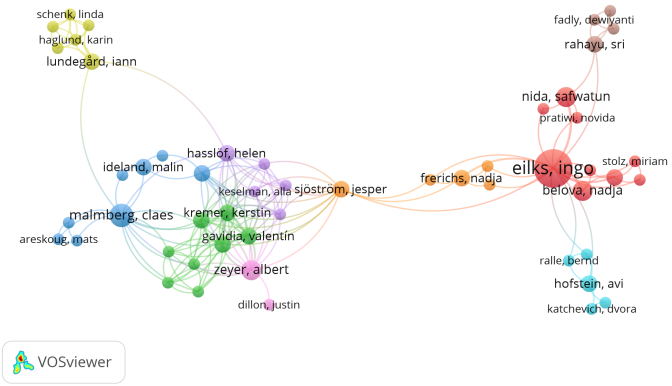

Figure 3. Map of SSI Researchers

During the period from 2004 to 2023, a total of 465 authors conducted and published research on SSI in education. Several authors published their findings more than once, contributing multiple papers on the topic. In addition, the published documents have received citations that serve as reference points for subsequent studies by other researchers. Based on the analysis results, the top 10 authors with the highest number of publications on SSI in science education are presented in Table 1.

Table 1. Top 10 Authors Published Document

Author	Document	Citation
Eilks, I	11	298
Sadler, T. D	4	417
Stavrou, D	4	50
Malmberg, C	4	22
Fensham, P.J	3	172
Zeidler, D I	3	105
Lee, H	3	95
Belova, N	3	49
Reis, Pedro	3	36
Sgouros, G	3	32

Based on the top 10 authors who have published the most on SSI in the Scopus database, the largest contributor is Eilks, with 11 documents that have been cited 298 times. Authors with four publications include Sadler, T. D., Stavrou, D., and Malmberg, C., with 417, 50, and 22 citations respectively. Meanwhile, authors such as Fensham, P. J., Zeidler, D. I., Lee, H., Belova, N., Reis, Pedro, and Sgouros, G. each contributed three publications, with citation counts of 172, 105, 95, 49, 36, and 32, respectively. There are also several other authors with three publications, but the ranking of the top 10 published authors was determined based on both the number of publications and citation counts.

3.1.2 Contribution of Countries and Affiliation

A total of 43 countries and 9 undefined-country articles contributed to SSI research in science education between 2004 and 2023. The concept of SSI literacy in education was first introduced by Red Fleming from Canada. As Canada is located in the Americas, SSI research has since become widely developed across the American continent. The map of country contributions to SSI research can be seen in Figure 4.

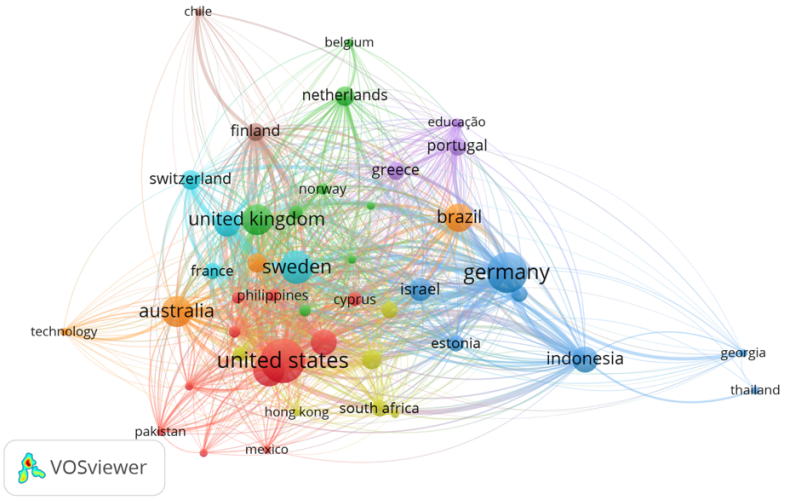

Figure 4. Mapping Contribution of Countries

Based on the research contributions from 43 countries, this study identifies the top 10 countries or territories with the highest number of publications on SSI in science education. The ranking of countries is determined by the number of published documents and the total citations received. The results of this ranking are presented in Table 2.

Table 2. Rank of Country by Document and Citation

Rank	Country by Documennt	Document	Rank	Country by Citation	Citation
1	United States	30	1	United States	868
2	Germany	25	2	Germany	495
3	Sweden	17	3	Sweden	315
4	Turkey	15	4	Turkey	234
5	United Kingdom	14	5	United Kingdom	231
6	Brazil	12	6	Brazil	104
7	Spain	10	7	Spain	89
8	Indonesia	10	8	Israel	59
9	Israel	8	9	Switzerland	50
10	Switzerland	6	10	Indonesia	40

The ten countries with the highest number of publications on SSI in science education in the Scopus database over the past 20 years are as follows: the United States, which contributed 14.42% of the total articles; followed by Germany, Sweden, Turkey, the United Kingdom, and Brazil, contributing 12.02%, 8.17%, 7.21%, 6.73%, and 5.77%, respectively. Indonesia and Spain each contributed the same proportion of SSI publications, at 4.81%. Meanwhile, Israel accounted for 3.85%, and Switzerland for 2.88%.

3.1.3 Document by Subject Area and Co-Occurrence Network of the Keywords

The analysis results of studies on Socio-Scientific Issues (SSI) in science education encompass 20 different subject areas. The purpose of this subject-area analysis is to identify fields that provide relevant information and data concerning SSI-related research topics within science education. The subject areas of SSI research in science education are illustrated in Figure 5.

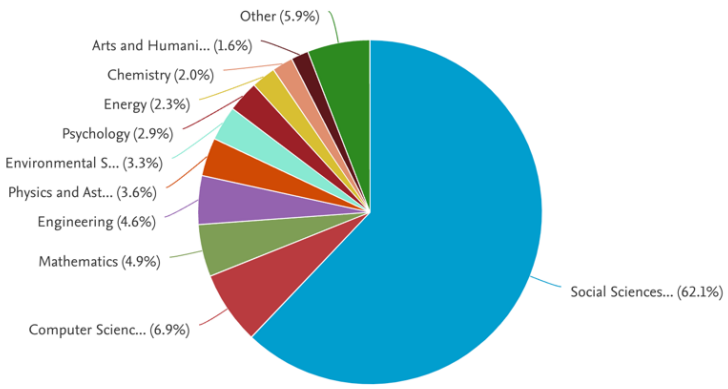

Figure 5. Subject Areas of SSI Research

Based on the analysis results, out of 208 Scopus-indexed documents, there are 20 identified research subject areas. The largest number of publications falls under Social Sciences, with a total of 190 documents. This is followed by Computer Science, Mathematics, Engineering, Physics and Astronomy, Environmental Science, Psychology, Energy, Chemistry, Arts and Humanities, and Business Management and Accounting, with 21, 15, 14, 11, 10, 9, 7, 6, 5, and 3 documents respectively. The subjects of Agricultural and Biological Sciences, Biochemistry, Genetics and Molecular Biology, Decision Sciences, Economics, Econometrics and Finance, Health Professions, and Medicine each contain 2 documents. Additionally, there are three subject areas with only one document each, namely Chemical Engineering, Immunology and Microbiology, and Multidisciplinary.

The subject-area analysis provides valuable insights into the types of articles published. Furthermore, there are a total of 720 keywords found across all 208 articles published in Scopus. All keywords were analyzed based on their frequency of occurrence within the research. The co-occurrence map of all keywords can be seen in Figure 6.

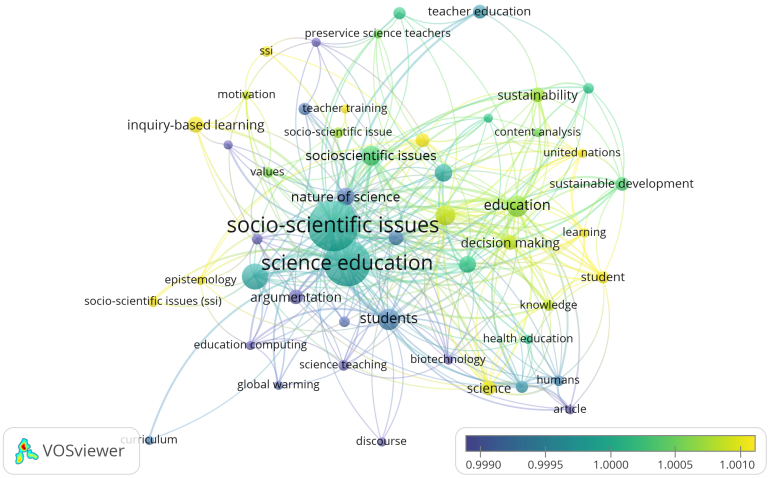

Figure 6. Mapping Occurrence of All Keywords

To identify the most frequent keywords, a minimum occurrence threshold was set for all terms. The selected criterion was a minimum of eight occurrences within SSI-related articles, resulting in the top 10 keywords presented in Table 3.

Table 3. Rank of Occurrence

Keywords	Occurences
Socio-scientific Issue	93
Science Education	68
Scientific Literacy	21
Education	15
Students	15
Teaching	13
Nature of Science	10
Environmental Education	10
Climate Change	9
Inquiry-based Learning	8

Based on the ranking of keyword occurrences, the most frequently appearing keyword is Socio-scientific Issue, accounting for 12.92%, followed by Science Education at 9.4%. Other dominant research keywords include Scientific Literacy, Education, Students, Teaching, Nature of Science, Environmental Education, Climate Change, and Inquiry-based Learning, with occurrence rates of 2.92%, 2.08%, 2.08%, 1.81%, 1.39%, 1.39%, 1.25%, and 1.11%, respectively. Therefore, the top 10 keywords based on occurrence rankings can be considered as representing the main research trends in SSI within science education over the past twenty years.

3.1.4 Source Articles on SSI

Scopus is an international, peer-reviewed journal database that includes a wide range of topics and diverse researchers. A total of 97 Scopus-indexed journals have published studies related to SSI research in science education. The mapping of SSI research sources in science education can be seen in Figure 7.

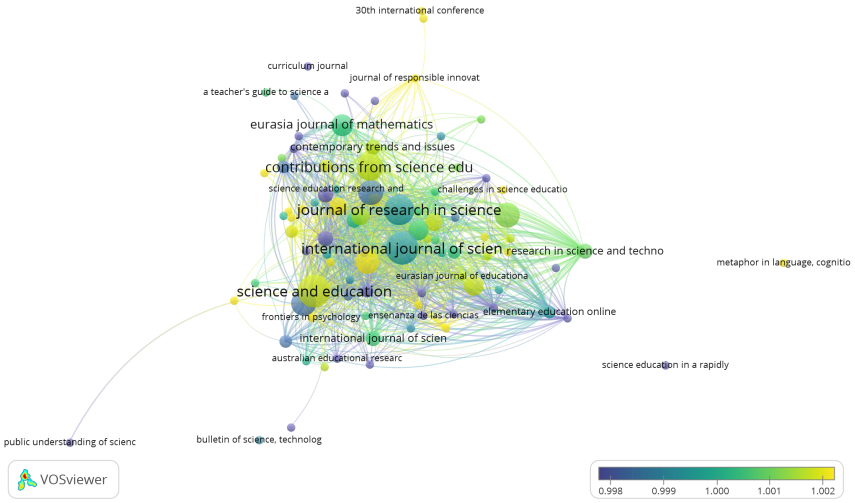

Figure 7. Map of SSI Sources in Science Education

Based on data obtained from 97 sources, 11 sources were identified as having the highest number of publications on SSI topics in science education. Ten of these sources are journals, while one is a journal from a conference series. The top 11 sources of SSI research are presented in Table 4.

Table 4. Top 11 Sources of SSI Research in Science Education

Source	Document	Citation
Science and Education	13	145
International Journal of Science Education	13	233
Journal of Research in Science Teaching	11	439
Contributions From Science Education Research	9	30
Cultural Studies of Science Education	8	115
Research in Science Education	8	171
Journal of Physics: Conference Series	8	0
Sustainablity (Switzerland)	7	67
Eurasia Journal of Mathematics, Science and Technology Education	6	137
Journal of Science Education and Technology	5	138
Investigacoes em Ensino de ciencias	5	4

3.1.5 Citation

Citations are an important factor in indicating research impact and emerging trends. A high number of citations in an article reflects researchers' interest in the study's topic and relevance. Research on SSI topics in science education comprises 208 Scopus-indexed articles published between 2004 and 2023. From these, the 10 most highly cited articles were selected and are presented in Table 5.

Table 5. Top 10 Article Citations

Rank	Document	Citation
1	Sadler (2009)	371
2	Chang (2010)	123
3	Fensham (2009)	118
4	Acar (2010)	77
5	Lee (2006)	71
6	Zeidler (2013)	68
7	Sjostrom (2017)	65
8	Hodson (2010)	58
9	Tsai (2018)	55
10	Eilks (2015)	54

1.2 Content Analysis

The following table presents a synthesis of selected key studies on Socio-Scientific Issues (SSI) in science education published over the past two decades. Each paper is summarized in terms of its study objective, methodology, main findings, and summary of discussion. These studies were selected based on their significant contributions to understanding how SSI can be integrated into science learning, as well as their exploration of its impact on students' skills, reasoning, and engagement.

Table 6 below outlines the diversity of approaches and findings from international SSI studies, providing insights into how SSI has been implemented across different contexts, disciplines, and educational levels.

Table 6. Summary of Key Studies on Socio-Scientific Issues (SSI) in Science Education

Paper	Study Objective	Methodology	Main Finding	Summary of Discussion
(Gutierez, 2015)	To improve students' bioethical decision-making, critical thinking, and scientific literacy, showing significant progress through t-test results.	The study used a quasi-experimental design with pretest and posttest on Grade 8 students, using a bioethics decision-making questionnaire tested beforehand.	Integrating SSI in biology lessons improves students' bioethical decision-making, boosts interaction and argumentation, and helps them make informed science-related decisions.	The study highlights that integrating SSI in science lessons improves students' decision-making and scientific literacy, with clear gains in bioethical decision-making skills.
(Capkinoglu et al., 2020)	The study evaluates how well students build arguments on local SSI topics, compares argument quality between groups, and identifies key takeaways from the results.	The study followed a multiple-case study design and included a pilot study and a 10-week data collection period. Field trips, newspapers, and presentations were	The main findings emphasize the significance of using argumentation for discussing controversial SSIs, the impact of different SSIs on argument quality, and the influence of data sources on students' argumentation quality.	The study found that students' argument skills differed by group. Those using newspapers performed best, while outdoor groups were weakest. Early discussions and reliable data help students make stronger arguments.

		used as learning sources.		
(Harris & Ratcliffe, 2005)	To explore students' participation in ethical discussions on biomedical and genetics topics and test the use of collapsed days to support SSI learning.	The study used a mixed-methods approach with data from teachers, students, and researchers across 11 schools to ensure complete and reliable results.	The CODA project showed that students enjoyed discussing biomedical ethics and genetics, though discussion quality varied and mostly stayed at basic levels like current affairs or simple debates.	The study highlights the need to engage students in ethical discussions and improve teachers' ability to guide them. It also notes that many students lack advanced discussion skills, so promoting exploratory talk in class is important.
(Kara, 2012)	Assess pre-service biology teachers' perceptions of SSI and the inclusion of SSI in classrooms, as well as to investigate the factors that might influence instructional practices related to SSI.	The study involved 102 pre-service biology teachers using questionnaires, analyzed with descriptive stats, reliability checks, and factor analysis.	Science teachers struggle to teach SSI because of personal values and conflicts with traditional content. The study highlights the need for teacher training on moral and ethical issues and explores how future teachers adapt to SSI teaching.	The study explains teachers' challenges in teaching SSI, stresses moral-ethical training, shows how school culture shapes beliefs, and calls for more research on SSI learning.
(Fensham, 2014)	Responding to Bryce and Day's paper on promoting scepticism in school science and challenging assumptions related to discussing climate change in school science.	Studying doubt-generating institutes and advocating for intellectual dependence in school science.	Increasing scientific certainty about human-induced global warming, emphasizes teaching scepticism in school science, and explores tactics used to generate public doubt about scientific issues.	The study stresses the need to teach students healthy scepticism in science, especially about issues like climate change, so they can judge when to question and when to trust scientific information.
(Colucci-Gray, 2014)	Explore citizens' attitudes towards global issues like global warming, stimulate reflection on implicit assumptions in the relationships between science, technology, and the public, and discuss the aims of school science education in relation to society and the environment.	The study uses multiple disciplines and perspectives to link science education with society, critique narrow scientific views, and recognize the social roots of SSI.	The development of reasoning competences in social settings, the importance of embracing diverse disciplines and narratives in science education, and the inseparability of knowledge from action and context.	The importance of developing reasoning competences in social settings, embracing diverse disciplines and narratives in science education, promoting critical judgment, and fostering dialogical exchanges across different ideas of development and worldviews.
(Zeidler et al., 2013)	The study examines how students from different cultures reason about socio-scientific issues, how cultural and scientific identities interact, and how these insights help build a model of SSI reasoning.	Mixed-methods design with over 300 students from five different countries engaging in discourse, argumentation, and debates around the topic of the allocation of scarce medical resources in relation to distributive justice.	Common themes in epistemological reasoning across cultures identified, significant differences in ability to raise scientifically relevant questions among countries, higher epistemological sophistication in Taiwanese students.	The consistent trend towards epistemological congruity across cultures in themes of fairness, pragmatism, emotive reasoning, utility, and theological issues, with a call for further research and the incorporation of virtue ethics approaches in science teaching.
(Sadler, 2009)	The study uses situated learning to prepare students for real-world science issues and reviews SSI research focused on interest,	Reviewing and synthesizing extant literature on SSI interventions, examining 24 studies meeting specific criteria,	The paper reviews existing literature on the effects of SSI interventions. It categorizes the results into themes like interest, content knowledge, nature of science, higher-	The paper emphasizes the importance of exploring how students negotiate complex socioscientific issues and develop socio-scientific Discourses and

	knowledge, thinking skills, and learning communities.	categorizing results, and considering the value of a situated learning perspective.	order thinking, and community of practice.	associated identities within classroom-based communities of practice.
(Santos, 2012)	Discuss concerns and scientific knowledge for the debate on climate change, address points between 'alarmists' and 'skeptics', and explore argumentation in the controversial debate on global warming.	The study involved a simulated debate where students assumed distinct roles and positions, video recording of lessons, and conducting debates in two different educational settings.	The paper emphasizes presenting the controversy, addressing political and economic issues, and understanding the greenhouse effect in the context of the global warming debate.	The need to present the controversy, address political and economic issues, understand the greenhouse effect, consider different political views in debates, and promote political literacy through discussions on global warming.
(Bryce & Day, 2014)	The study examines the complex debates on climate change, media conflicts, scientific consensus, and how teachers can approach teaching global warming.	A critical analysis of the challenges faced by science teachers in teaching about climate change, emphasizing the importance of skepticism and critical thinking in science education.	Critical examination of the climate science debate and controversies, challenges in teaching about the provisional nature of scientific knowledge, and the importance of developing skepticism and scientific literacy in students.	The importance of fostering scientific scepticism, teaching students to think like scientists, utilizing cooperative learning for climate change discussions, and encouraging intellectual scepticism among students.
(Kilinc et al., 2017)	To examine why a pre-service science teacher resisted using dialogue in SSI teaching and identify factors that caused this resistance to change.	Administering a questionnaire with vignettes, following a single-case design, and using various stages of data analysis and interpretation.	• The argumentation-based workshop led to mixed results in changing Duygu's beliefs about dialogic discourse, with some changes and some resistance. • Adverse experiences during the teaching practicum increased Duygu's resistance and caused a reversal of her previous positive beliefs.	Resistance to change is a complex process that goes beyond pedagogical limitations and inconsistencies between core beliefs and reform expectations, requiring a comprehensive approach in professional development to address first- and second-order barriers for effective science and SSI teaching.
(Slovinsky et al., 2021)	The study examines how context-based science modules affect student motivation and how gender and context influence their learning experience.	Quasi-experimental design, data collection using the MoLE questionnaire, analysis of wish-to-reality differences, and comparison of mean changes between different groups using t-tests.	The context-based socio-scientific science teaching intervention led to increased satisfaction and class cooperation among students, suggesting a positive impact on students' motivation and interest in science education.	The study shows that context-based SSI teaching increases students' motivation and interest in science. It also highlights the need for ongoing teacher training and confirms the MoLE tool's usefulness for future motivation research.
(Ram, 2020)	The study explores how to engage young people in learning about biosecurity, understand their views, and include real socio-scientific issues in teaching.	The study used a qualitative approach with two multicultural schools in Auckland, analyzing students' understanding of biosecurity through thematic coding.	The study found that young people felt emotionally connected to biosecurity topics but struggled to understand them fully. It recommends building prior knowledge and teaching biosecurity as a socio-scientific issue to make learning more effective.	The study highlights the need to teach biosecurity in schools to re-engage students with science and help them make informed decisions.
(Hansson et al., 2011)	Describe the digital learning environment with an Astrobiology context, report the results of students'	The importance of science knowledge in decision-making on socio-scientific issues, referencing a	Defining socio-scientific issues, student groups' decisions on extraterrestrial life and Mars terraforming, and the prevalence of science-	The study shows that students used science-based arguments in SSI decision-making, which helps improve their

	decisions on socio-scientific driving questions, and highlight the importance of scaffolding for effective reasoning.	study where students did not use science content learned in school, and highlighting the influence of values and worldviews on decisions.	related support in final standpoints.	understanding of science concepts.
(Sorensen et al., 2016)	Create a framework that links biophysical and social sciences, test how social/environmental evidence shapes climate-change understanding, build a human–climate model, map claims and evidence, and design a way to assess students' practices.	The study develops a model to teach climate adaptation and mitigation by integrating biophysical and social science knowledge, focusing on the early stages of building this framework.	The development of a knowledge framework for integrating biophysical and social science domains, the unique use of a model for guiding and assessing interdisciplinary instruction at the collegiate level, and a focus on the initial stages of building a model of human-climate dynamics.	The study explains that social science models are more uncertain than biophysical ones. It highlights the use of inductive reasoning—drawing conclusions from data without fixed theories—and notes that predictions often have wide uncertainty ranges.
(Wolff & Mnguni, 2015)	Examine how SSIs especially HIV/AIDS are integrated into South Africa's secondary Life Sciences curriculum and to what extent related skills are taught.	The study used qualitative document analysis to examine how HIV/AIDS content and 21st-century skills are included in South Africa's Life Sciences curriculum.	The Life Sciences curriculum in South Africa lacks substantial HIV/AIDS content and does not effectively guide students and teachers to reliable resources for learning about HIV/AIDS and developing related skills. Overall, the curriculum is not effectively utilized to teach content knowledge related to socio-scientific issues.	The study found that HIV/AIDS content is minimally included in the Life Sciences curriculum, with most focus on immunity topics. It emphasizes the need to revise the curriculum to include more SSI-related content.
(Lindahl et al., 2019)	The study explores how students understand knowledge, their challenges in meeting learning goals in the SinC curriculum, and its contribution to science education research.	The study examines how students understand knowledge in flexible contexts and how recognizing learning demands helps them connect different ideas in SSI discussions.	Students who lacked recognition skills struggled to connect ideas, saw SSI tasks as irrelevant, and kept personal and academic views separate, making learning harder.	The study found that students often had trouble connecting science with real-life issues. Many saw SSI tasks as irrelevant or relied on others' opinions. This shows the need for guidance to help students relate scientific ideas to everyday life.

4. DISCUSSION

References to Socio-scientific Issues (SSI) in the development of science education indicate that SSI emerged as a replacement for STS (Science, Technology, and Society), which has a broader scope (Levinson, 2013). Consequently, SSI has remained relatively unfamiliar to many researchers, as studies in the intersection of social and scientific contexts have traditionally relied on the STS or SETS (Science, Environment, Technology, and Society) frameworks. While the STS innovation represented a major breakthrough in school science curricula, it also presented various challenges. Therefore, the transformation from STS to SSI was initiated by Zeidler, Sadler, Simmons, and Howes in 2005, who argued that SSI offers a broader theoretical framework emphasizing individual development, student morality and ethics, and the epistemological stance of SSI—factors that differentiate SSI from STS (Levinson, 2013).

Publications on SSI research in science education based on the Scopus database over the past twenty years show a steady increase. In the last five years, SSI studies have risen

significantly, largely due to the COVID-19 pandemic, which led to a shift in instructional paradigms toward integrating learning with environmental and societal contexts. The United States remains the leading country contributing to SSI research in science education, and thus global trends in this area often follow the developments originating from the U.S.

Researchers have implemented SSI to measure various key skills that have become research trends. The most frequently assessed skills through SSI-based implementation include scientific literacy (Badeo & Duque, 2022), argumentation (Capkinoglu et al., 2020), problem-solving (Gutierez, 2015; Patronis & Spiliotopoulou, 1999), and scientific reasoning (Aziz & Johari, 2023; Hansson et al., 2011; Sorensen et al., 2016). The most common SSI research topics include mathematics, physics and astronomy, engineering, environmental science, energy, chemistry, and arts and humanities. Earlier SSI studies primarily focused on argumentation and reasoning; however, in recent years, SSI has been increasingly applied in science education to enhance students' scientific literacy (Badeo & Duque, 2022).

Scientific literacy has become the most frequently examined topic in SSI research. The use of SSI in education plays a crucial role in improving students' scientific literacy (Gutierez, 2015). Scientific literacy encompasses two key dimensions: understanding ideas within a scientific context and understanding those ideas within real-world contexts that are scientific in nature but influenced by social, political, and ethical factors (Badeo & Duque, 2022). Therefore, the current trend in SSI research largely focuses on the study of scientific literacy. This topic is not only vital in the field of education but also highly relevant to SSI-based research.

Discussions surrounding SSI emphasize the importance of integrating socio-scientific issues into science education. SSI in biology instruction, for instance, has been shown to significantly enhance students' bioethical decision-making skills. Classroom interactions and argumentation among students can improve substantially when socio-scientific issues are embedded within lessons. Argumentation plays a critical role in addressing controversial SSI topics, as it directly affects the quality of students' reasoning. Moreover, it influences the types of data sources students rely on, thereby improving the overall quality of their arguments.

SSI-based learning is highly supportive of science education, but teachers often face challenges in managing SSI due to its controversial nature, which can make integration with core scientific content difficult. Consequently, the most frequently explored SSI topic is human-induced global warming, as it allows students to examine tactics and strategies for addressing real-world issues. Developing reasoning competence within a social context is essential in SSI discussions, as science education requires the integration of multiple disciplines and narratives. This integration ensures that knowledge, action, and context are inseparably connected in the learning process.

5. CONCLUSION

The trend of SSI research over the past twenty years (2004–2023) has shown a highly significant increase, particularly within the last five years. The United States has been the country contributing the most to SSI research. The most frequently examined impacts of SSI in science education include the development of scientific literacy, argumentation, reasoning, and problem-solving skills. The most commonly studied SSI topics are global warming and climate change. SSI has had a substantial influence on science education, leading to a surge of international research in recent years focused on its implementation and outcomes. However, the main challenge lies in teachers' ability to effectively integrate SSI into science instruction,

as doing so requires both pedagogical competence and the capacity to address complex, controversial issues within the classroom context.

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