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Mapping socioscientific issues research in science education: Trends, pedagogy, competencies, and gaps (2021–2025)

Rif'at Shafwatul Anam [a] *, Ahmad Yani [b]

Universitas Terbuka, Jl. Cabe Raya, Pondok Cabe, Pamulang, Tangerang Selatan, Indonesia
[a] rifat.official@ecampus.ut.ac.id; [b] ahmad.official@ecampus.ut.ac.id
* Corresponding Author

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Abstract: Amid increasing global challenges characterized by uncertainty, complexity, and ethical dilemmas, socioscientific issues (SSI) have emerged as a critical framework for advancing science education. This study systematically examines research trends, pedagogical approaches, competencies, and research gaps in SSI studies. A systematic literature review (SLR) was conducted using the PRISMA protocol on 53 open-access articles published between 2021 and 2025 in selected high-impact Scopus Q1 journals. The findings reveal a growing concentration of SSI research within the selected corpus, particularly in recent publications. Qualitative approaches dominate, with studies largely situated in secondary and higher education contexts. Research primarily focuses on environmental and health-related issues, while argumentation, inquiry-based learning, and discussion are the most frequently applied pedagogical approaches. SSI-based learning fosters multidimensional competencies across cognitive, epistemic, and affective domains. However, key gaps persist, including limited thematic diversity, underrepresentation of primary education, insufficient integration of emerging technologies, and a lack of large-scale and longitudinal designs. This study underscores the need for broader implementation, methodological diversification, and technology integration. Limitations related to the bounded corpus and open-access selection are acknowledged, which may affect generalizability.
Keywords: socioscientific issues; science education; systematic literature review; PRISMA; scientific literacy

INTRODUCTION

The rapid advancement of science and technology in the 21st century has fundamentally transformed how individuals understand and respond to increasingly complex global challenges. Issues such as climate change, pandemics, environmental crises, and developments in biotechnology can no longer be viewed as purely scientific and value-neutral phenomena; rather, they are multidimensional problems that involve social, ethical, economic, and political considerations. This complexity has led to the emergence of socioscientific issues (SSI), which are defined as controversial, real-world problems grounded in science that require individuals to engage in critical reasoning, moral evaluation, and informed decision-making (Sadler & Zeidler, 2004; Zeidler & Nichols, 2009). Positioned at the intersection of science and society, SSI plays a crucial role in science education by fostering learners' ability to evaluate evidence, consider

multiple perspectives, and make responsible decisions in contexts characterized by uncertainty and complexity (Zeidler et al., 2005; Zeidler & Nichols, 2009).

In this context, SSI has evolved into a strategic pedagogical approach aligned with the demands of 21st-century learning. Rather than treating science as a static body of knowledge, SSI positions it as a dynamic and socially embedded practice. Through SSI-based instruction, students are encouraged to engage in argumentation, inquiry, and evidence-based reasoning as they interact with authentic societal issues (Dawson, 2024; Smith et al., 2025). Moreover, SSI learning environments promote dialogic interaction and democratic participation, enabling learners to construct understanding when addressing controversial issues collaboratively (Bossér & Lindahl, 2021; Ottander & Simon, 2021). Empirical studies further indicate that SSI contributes to the development of multidimensional competencies, encompassing cognitive (scientific literacy and conceptual understanding), epistemic (evaluation of evidence and understanding of the nature of science), and affective domains (values, ethics, and social responsibility) (Covitt & Anderson, 2022; Tuncay-Yüksel et al., 2023).

As scholarly interest in SSI continues to grow, research in this field has expanded significantly and become increasingly multidimensional. Recent studies have explored diverse aspects of SSI, including argumentation, critical thinking, misinformation, civic engagement, and climate change education (Baltikian et al., 2025; Cagle et al., 2025; Johnson et al., 2025; Pimentel, 2025). However, despite this expansion, the existing body of literature remains fragmented, often focusing on specific variables or localized contexts without providing an integrative understanding of research trends, pedagogical approaches, and competency development.

Although several review studies have been conducted, they tend to examine SSI from limited perspectives and rarely integrate multiple analytical dimensions simultaneously (e.g.,Högström et al., 2025). Furthermore, there is still limited evidence synthesizing recent SSI research based on high-quality publications from Scopus Q1 journals. This gap indicates the need for a more comprehensive and systematic review that not only maps research trends but also connects methodological characteristics, pedagogical approaches, competency development, and research gaps within a unified analytical framework.

Based on this rationale, the present study aims to conduct a systematic literature review (SLR) of SSI-related articles published in selected high-impact Scopus Q1 journals between 2021 and 2025. This study seeks to provide a structured synthesis of research trends, pedagogical practices, competencies developed, and existing research gaps. In doing so, it contributes to a more coherent understanding of SSI research and offers directions for future studies in science education.

In terms of methodological contribution, this study applies the PRISMA protocol combined with a manual archive-based retrieval strategy. While this approach allows for a more targeted and context-sensitive identification of relevant articles, it is also implemented with clearly defined inclusion criteria to minimize potential selection bias. By focusing on recent publications, this study provides a state-of-the-art overview of SSI research while maintaining methodological transparency and rigor.

METHODS

Research Design

This study employed a Systematic Literature Review (SLR) guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework

(Page et al., 2021). The PRISMA protocol was adopted to ensure that the processes of identification, screening, eligibility assessment, and inclusion of articles were conducted systematically, transparently, and replicably. Compared to traditional narrative reviews, the use of PRISMA enhances methodological rigor by improving transparency and reducing potential bias in the selection process.

Furthermore, the inclusion of open-access articles was determined as a methodological criterion to ensure full-text accessibility, enabling comprehensive content analysis and minimizing potential bias from incomplete data. It is acknowledged that this approach may exclude relevant non-open-access studies; however, it enhances transparency, consistency, and analytical depth within the selected corpus

It is important to note that this study is a systematic review of a bounded corpus, as the data were purposively selected from high-impact Scopus Q1 journals in science education. This approach was intentionally applied to ensure the inclusion of high-quality and relevant studies; however, it does not aim to represent the entire landscape of SSI research. The selection of an SLR design was motivated by the need to synthesize a rapidly growing yet fragmented body of SSI research in a structured and integrative manner. By focusing on a clearly defined corpus, this study provides a more in-depth and context-sensitive analysis of research trends, pedagogical approaches, competency development, and research gaps in SSI studies.

Data Sources

The dataset consisted of articles published in Scopus-indexed Q1 international journals in science education. Seven leading journals were selected: Cultural Studies of Science Education (CSSE), International Journal of Science and Mathematics Education (IJSME), International Journal of Science Education (IJSE), Journal of Science Education and Technology (JSET), Journal of Research in Science Teaching (JRST), Research in Science & Technological Education (RSTE), and Science & Education (SE).

These journals were purposively selected based on three main considerations: (1) their high academic reputation and impact as indicated by SCImago Journal Rank (SJR), (2) their strong and consistent publication record in science education research, particularly in areas closely related to socioscientific issues (SSI), and (3) their thematic relevance to the scope of this study. While other journals in science education may also publish SSI-related research, this study deliberately focuses on a bounded and clearly defined corpus to enable a more in-depth and coherent analysis.

These journals were purposively selected due to their high academic reputation and strong impact as indicated by their SCImago Journal Rank (SJR). Focusing on Q1 journals ensures that the included studies represent high-quality and influential contributions to the field, thereby strengthening the validity and credibility of the review findings.

Search Strategy and Article Selection

An archive-based manual retrieval strategy was employed by accessing each journal's official website. To improve search comprehensiveness, a broader keyword string was used, including variations such as "socioscientific issues", "socioscientific issues", "socioscientific issue", "socioscientific issues", and related terms. The search was conducted across the title, abstract, and keywords of each article to ensure both precision and relevance.

The search was limited to publications from 2021 to 2025, and data collection was completed in February 2026 to capture recent developments in SSI research. The selection process followed the four stages of the PRISMA framework: identification, screening, eligibility, and inclusion. A total of 238 articles were identified. During screening, 150 closed-access articles were excluded, resulting in 88 open-access articles. In the eligibility stage, 35 articles were excluded for relevance, leaving 53 for final analysis.

It is acknowledged that restricting the dataset to open-access articles may introduce corpus bias and limit the representativeness of the findings. However, this criterion was applied to ensure full-text accessibility and to enable a consistent, in-depth content analysis. The complete selection process is presented in the PRISMA flow diagram (Figure 1).

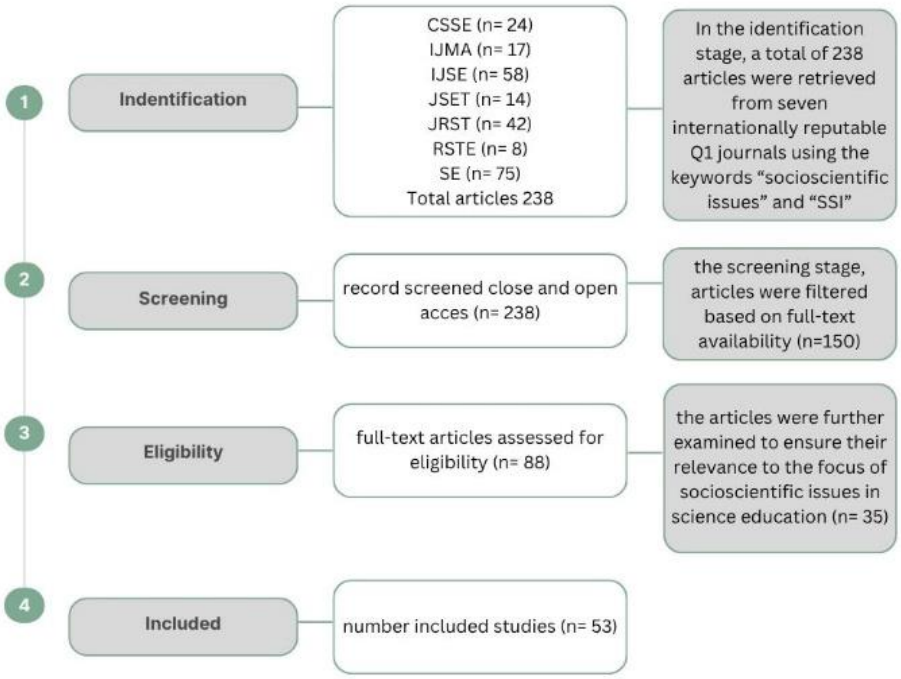

Figure 1. PRISMA Flow Diagram for Article Selection

Inclusion and Exclusion Criteria

The inclusion criteria were: (1) articles explicitly addressing socioscientific issues in science education, (2) empirical studies or systematic reviews, (3) open-access articles, and (4) publications from 2021–2025. The exclusion criteria included: (1) studies not relevant to SSI, (2) editorial articles, commentaries, or book reviews, (3) duplicate records, and (4) closed-access articles, as restricted access limits comprehensive full-text analysis. The decision to include only open-access articles was not merely practical but methodological, ensuring transparency, accessibility, and depth of analysis across all selected studies

Data Analysis and Coding Scheme

Data were analyzed using qualitative content analysis with a deductive coding approach (directed qualitative content analysis), guided directly by the research questions. This approach enables systematic classification of data while maintaining analytical rigor in identifying patterns aligned with predefined categories.

The coding scheme was designed to capture multiple analytical dimensions, including publication trends, methodological characteristics, educational levels, SSI themes, pedagogical approaches, competency domains (cognitive, epistemic, and affective), and research gaps. This multi-layered framework enables a comprehensive, integrative analysis, addressing limitations in previous SSI reviews that often focused on a single dimension. The detailed coding scheme is presented in Table 1.

Tabel 1. Coding Scheme for Data Analysis

Research Questions	Category	Code
RQ1	Publication Year	2021, 2022, 2023, 2024, 2025
RQ2	Research Methods	Quantitative, Qualitative, Mixed Methods, Review
	Educational Level	Primary, Secondary, Higher Education, Teacher Education
RQ3	SSI Topics	Climate Change, Health, Environment, Biotechnology, Sustainability, Ethics
	Pedagogical Approaches	Argumentation, Inquiry, Problem-Based Learning, Role-Play, Discussion
RQ4	Cognitive	Conceptual Understanding, Scientific Literacy
	Epistemic	Nature of Science (NOS), Evidence Evaluation, Reasoning
	Affective	Attitudes, Values, Social Awareness, Responsibility
RQ5	Research Gap Focus	Underexplored Topics, Methodological Limitations
	Contextual Gap	Limited research at the primary education level and insufficient integration of technology

Development of the Coding Scheme and Reliability

The coding scheme was developed collaboratively by a team of three researchers with over ten years of experience in education research. Each researcher systematically: (1) verified the relevance of article titles, (2) examined abstracts for contextual alignment, and (3) analyzed research methods in depth. All articles were coded using an agreed-upon open coding system. To ensure the robustness of the coding framework, the researchers evaluated whether the categories adequately represented the analytical scope of the study.

To establish reliability, each researcher independently coded the articles. Inter-coder agreement was calculated by assigning a score of one (1) for agreement and zero (0) for disagreement, then computing the proportion of agreement across all coding instances. Following established conventions (Miles et al., 2014, as cited in Caramaschi et al., 2022), an agreement level above 80% indicates acceptable reliability. The analysis yielded a 100% agreement rate, indicating a very high level of consistency and confirming the clarity and operational validity of the coding scheme. This result strengthens the credibility, dependability, and confirmability of the study.

Analytical Procedure

The overall analytical procedure consisted of five stages: (1) article identification, (2) screening based on inclusion and exclusion criteria, (3) in-depth content analysis, (4) coding using the developed framework, and (5) synthesis of findings to identify patterns, trends, and research gaps. This structured and rigorous approach ensures that the findings are comprehensive, systematically derived, and aligned with the objectives of the study, thereby contributing meaningful insights into the development of socioscientific issues research in science education.

It should be noted that a formal quality appraisal of individual studies was not conducted. This decision was based on selecting articles from high-impact Scopus Q1

journals, which are generally subject to rigorous peer review. However, the absence of a detailed quality assessment may limit the ability to evaluate the methodological robustness of each study. Therefore, the findings of this review should be interpreted with consideration of this limitation. Future research is recommended to incorporate formal quality appraisal tools (e.g., CASP or similar frameworks) to strengthen further the methodological rigor of systematic reviews in this field.

RESULT AND DISCUSSION

This section presents the findings of the systematic literature review based on the predefined research questions. The analysis is organized into five main parts, each addressing a specific aspect of socioscientific issues (SSI) research in science education.

First, the distribution of articles is examined to identify publication trends over time and across journal sources (RQ1). Second, the methodological approaches and educational levels employed in SSI studies are analyzed (RQ2). Third, the thematic focus and learning approaches used in the studies are explored (RQ3). Fourth, the competencies developed through SSI-based learning are identified (RQ4). Finally, the analysis highlights existing research gaps to provide directions for future studies (RQ5).

Through this structured analysis, the findings offer a comprehensive overview of the current state and development of SSI research in high-impact science education journals.

RQ1. Distribution of SSI Research by Publication Year and Journal Source

To address the first research question, this study analyzes the distribution of socioscientific issues (SSI) research based on publication year and journal source. This analysis is essential to identify both temporal trends and the concentration of research within high-impact journals in science education. The distribution of articles by publication year is presented in Table 2.

Tabel 2. Distribution of Articles by Publication Year

Year	Authors	Number of Articles	Percentage (%)
2021	(Bossér & Lindahl, 2021; Christodoulou et al., 2021; Dunlop et al., 2021; García-Carmona, 2021; Garrecht et al., 2021; Ottander & Simon, 2021)	6	11.32
2022	(Covitt & Anderson, 2022; Park et al., 2022; Rautio et al., 2022)	3	5.66
2023	(Bächtold et al., 2023; Ballard et al., 2023; Garrecht et al., 2023; Garthwaite et al., 2023; Gisewhite, 2023; Ha et al., 2023; Leung & Cheng, 2023; Park et al., 2023; Tofel-Grehl, 2023; Tuncay-Yüksel et al., 2023)	10	18.87
2024	(Dawson, 2024; Herman et al., 2024; Kolstø et al., 2024; Krell et al., 2024; Park et al., 2024; Rasa et al., 2024; Steube et al., 2024)	7	13.21
2025	(Agustian, 2025; Baltikian et al., 2025; Bautista, 2025; Ben Zvi Assaraf et al., 2025; Cagle et al., 2025; Christodoulou & Grace, 2025; Durak & Topçu, 2025; Gandolfi, 2025; Garrecht & Adler, 2025; Högström et al., 2025; Imaduddin et al., 2025; Johnson et al., 2025; Lymbouridou, 2025; Miani et al., 2025; Morales-Doyle & Rajski, 2025; Newton & Annetta, 2025; Park et al., 2025; Pimentel, 2025; Şen & Öztuna Kaplan, 2025; Smit et al., 2025; Smith et al., 2025; Teshera-Levye et al., 2025; Tofel-Grehl et al., 2025; Tolbert et al., 2025; Vicente et al., 2025; Viciana et al., 2025; Yavuzkaya et al., 2025)	27	50.94
	Total	53	100%

As shown in Table 2, SSI research demonstrates a clear and substantial upward trend over the five-year period. The number of publications remains relatively low in the early years, particularly in 2022 (5.66%), before increasing significantly in 2023 (18.87%) and continuing to grow in 2024 (13.21%). The most notable surge occurs in 2025, which accounts for more than half of the total publications (50.94%).

This sharp increase indicates that SSI has gained significant attention as a research focus in recent years. The growing number of publications in 2025 reflects the urgency of integrating SSI into science education to address complex global challenges, including climate change, environmental sustainability, and ethical decision-making. Recent studies illustrate this trend by focusing on ethical dimensions of science (Lymbouridou, 2025), social justice perspectives in science teaching (Bautista, 2025), and cognitive aspects of socioscientific decision-making (Garrecht & Adler, 2025). Furthermore, research has increasingly explored students' engagement with climate-related issues and scientific civic participation (Baltikian et al., 2025; Tolbert et al., 2025). To further understand this trend, the distribution of articles was also analyzed based on journal sources across each year, as presented in Table 3.

Tabel 3. Distribution of SSI Articles by Year and Journal Source

Year	CSSE	IJSME	IJSE	JSET	JRST	RSTE	SE	Total
2021	2	1	3	0	0	0	0	6
2022	1	0	1	0	0	0	1	3
2023	2	0	1	0	4	0	3	10
2024	2	1	1	0	2	0	1	7
2025	3	0	5	2	5	0	12	27
Total	10	2	11	2	11	0	17	53

The cross-analysis reveals that the increase in SSI publications is strongly driven by specific journals. Science & Education (S&E) emerges as the most dominant contributor, particularly in 2025, indicating its central role in disseminating research related to ethical, philosophical, and socio-cultural aspects of science education (Agustian, 2025; Gandolfi, 2025; Imaduddin et al., 2025).

Similarly, International Journal of Science Education (IJSE) and Journal of Research in Science Teaching (JRST) show consistent contributions across multiple years, highlighting their importance as core journals in the field. Studies in IJSE frequently address issues such as argumentation and climate change education (Ben Zvi Assaraf et al., 2025; Dawson, 2024), while JRST publications emphasize epistemic practices and misin-formation in science learning (Cagle et al., 2025; Pimentel, 2025).

In contrast, Research in Science & Technological Education (RSTE) does not contribute any articles within the selected dataset, suggesting a potential gap in its engagement with SSI-related topics. Meanwhile, Journal of Science Education and Technology (JSET) shows emerging participation, particularly in 2025, with studies focusing on technology-enhanced SSI learning (Tofel-Grehl, 2023).

The dominance of publications in 2025 also reflects a broader shift toward integrating SSI into contemporary educational priorities, including sustainability education, environmental citizenship, and interdisciplinary learning. For example, recent studies explore environmental responsibility (Christodoulou & Grace, 2025), ethical decision-making through role-play (Vicente et al., 2025), and future-oriented scientific literacy (Rasa et al., 2024).

Overall, the findings indicate that SSI research is experiencing rapid growth, with a strong concentration in leading international journals. This trend underscores the in-

creasing recognition of SSI as a central framework in science education for developing critical thinking, ethical reasoning, and socially responsible scientific literacy.

RQ2. Research Methods and Educational Levels in SSI Studies

To address the second research question, this study systematically examined the research methods and educational levels employed across the 53 selected articles on socioscientific issues (SSI) in science education. The results reveal distinct patterns in both methodological preferences and the distribution of research contexts, as presented in Table 4.

Tabel 4. Distribution of Research Methods and Educational Levels in SSI Studies

Category	Sub-category	Number of Articles	Percentage (%)
Research Methods	Qualitative	28	52.83
	Quantitative	8	15.09
	Mixed Methods	10	18.87
	Review	7	13.21
Total		53	100
Educational Levels	Primary	4	7.55
	Secondary	21	39.62
	Higher Education	18	33.96
	Teacher Education	10	18.87
Total		53	100

Research Methods

The results indicate that qualitative research dominates SSI studies, accounting for more than half of the total articles (52.83%). This dominance reflects the inherent nature of SSI, which involves complex interactions between scientific knowledge, ethical considerations, and social contexts. Qualitative approaches are particularly suitable for exploring students' reasoning, argumentation, and decision-making processes in depth. For example, studies by Leung & Cheng (2023) examine emotional dimensions in SSI learning, while Garrecht et al (2023) investigate ethical reasoning and socioscientific argumentation.

Mixed-methods studies (18.87%) also represent a significant portion of the literature, indicating an increasing effort to integrate quantitative rigor with qualitative depth. These studies provide a more comprehensive understanding of SSI by combining statistical analysis with contextual insights.

In contrast, quantitative studies (15.09%) are less prevalent and tend to focus on measurable outcomes such as students' attitudes, scientific literacy, and argumentation skills. For instance, Baltikian et al (2025) analyze students' attitudes toward climate change urgency, while Smit et al (2025) examine the impact of SSI approaches on self-efficacy and interest in science.

Additionally, review-based studies (13.21%), including systematic and scoping reviews, contribute to consolidating existing knowledge and identifying broader research trends. Examples include the work of Högström et al (2025) and Tofel-Grehl et al (2025). Overall, the methodological distribution suggests that SSI research is still largely exploratory and interpretive, with a growing but still limited presence of quantitative validation.

Educational Levels

In terms of educational levels, the findings show that SSI research is predominantly conducted at the secondary education level (39.62%), followed by higher education

(33.96%). This trend indicates that SSI is most frequently implemented in contexts where students are considered cognitively ready to engage in complex reasoning, argumentation, and decision-making processes.

At the secondary level, studies often focus on developing students' argumentation skills and socioscientific reasoning. For example, Dawson (2024) examines teacher support in fostering students' argumentation on SSI topics. Meanwhile, higher education studies frequently involve undergraduate students and emphasize advanced competencies such as critical thinking and civic engagement.

A notable portion of studies (18.87%) focuses on teacher education, particularly preservice teachers. Research by Krell et al (2024) and Vicente et al (2025) highlights the importance of preparing future educators to effectively implement SSI-based instruction.

In contrast, primary education (7.55%) remains underrepresented. Only a few studies, such as Kolstø et al (2024), explicitly explore SSI in elementary school contexts. This limited representation suggests that the integration of SSI at early educational stages has not been widely explored.

The combined results indicate that SSI research is characterized by a strong preference for qualitative methodologies and a concentration in secondary and higher education contexts. While this aligns with the complex and interdisciplinary nature of SSI, it also reveals an imbalance in both methodological diversity and educational coverage. The relatively limited number of quantitative studies and the underrepresentation of primary education contexts highlight important areas for future research development.

RQ3. Thematic Focus and Instructional Approaches in SSI Research

To address the third research question, this study examines the thematic focus of socioscientific issues (SSI) and the instructional approaches employed in the 53 selected articles. This analysis aims to identify dominant topics as well as the pedagogical strategies used to facilitate SSI-based learning in science education. The findings indicate clear trends in both the selection of SSI themes and the implementation of instructional approaches, which are systematically presented in Table 5.

Tabel 5. Distribution of SSI Topics and Instructional Approaches in Selected Studies

Category	Sub-category	Number of Articles	Percentage (%)
SSI Topics	Climate Change	12	22.64
	Health (e.g., Covid-19)	8	15.10
	Environment & Sustainability	14	26.42
	Biotechnology	5	9.43
	Ethics & Moral Issues	9	16.98
	Others (e.g., politics, risk)	5	9.43
Total		53	100
Instructional Approaches	Argumentation	15	28.30
	Inquiry-Based Learning	8	15.10
	Problem-Based Learning	7	13.21
	Role-Play/Simulation	6	11.32
	Discussion-Based Learning	12	22.64
	Techology-Enchanced Learning	5	9.43
Total		53	100

Thematic Focus of SSI

The analysis indicates that environmental and sustainability issues (26.42%) constitute the most dominant theme in SSI research. These topics often include biodiversity loss, environmental crises, and sustainability education. Studies such as those by Christodoulou & Grace (2025) highlight environmental citizenship, while Rasa et al (2024) explore futures thinking in sustainability contexts.

Climate change (22.64%) emerges as another major focus, reflecting its global urgency and relevance in science education. Research by Baltikian et al (2025) and Ben Zvi Assaraf et al (2025) demonstrates how climate-related SSI are used to foster scientific literacy and civic engagement.

The health domain (15.10%), particularly studies related to COVID-19, also represents a significant portion of the literature. For example, Krell et al (2024) and Şen & Öztuna Kaplan (2025) examine socioscientific reasoning in the context of vaccination and pandemic-related issues.

In addition, ethical and moral issues (16.98%) are frequently embedded within SSI studies. Research by Garrecht et al (2023) and Tuncay-Yüksel et al (2023) emphasizes ethical reasoning and moral judgment as central components of SSI learning. Meanwhile, biotechnology (9.43%) and other emerging topics such as risk perception and political dimensions of science remain less explored, indicating opportunities for further research expansion.

Instructional Approaches in SSI

The findings show that argumentation-based approaches (28.30%) are the most widely used instructional strategy in SSI research. This aligns with the nature of SSI, which requires students to justify claims, evaluate evidence, and engage in reasoned debate. Studies by Dawson (2024) and Bächtold et al (2023) exemplify the use of argumentation to enhance students' reasoning skills.

Discussion-based learning (22.64%) is also highly prevalent, often implemented through classroom dialogue and collaborative meaning-making. For instance, Ottander & Simon (2021) explore democratic participation through SSI discussions.

Inquiry-based learning (15.10%) and problem-based learning (13.21%) are used to engage students in investigating real-world problems and constructing knowledge actively. These approaches emphasize student-centered learning and critical thinking.

Furthermore, role-play and simulation (11.32%) are employed to immerse students in complex decision-making scenarios. Research by Vicente et al (2025) demonstrates how role-playing can enhance argumentation and ethical reasoning.

Finally, technology-enhanced learning (9.43%) appears as an emerging trend, particularly in studies integrating digital tools, simulations, or extended reality. For example, Newton & Annetta (2025) investigate the role of extended reality in climate change education.

The results indicate that SSI research is strongly oriented toward environmental and climate-related issues, reflecting global educational priorities. In terms of pedagogy, there is a clear emphasis on argumentation and discussion-based approaches, which support the development of critical and reflective thinking.

However, the relatively lower proportion of studies in biotechnology and technology-enhanced learning suggests that these areas remain underexplored. This imbalance highlights the need for broader thematic diversification and increased integration of innovative instructional approaches in future SSI research.

RQ4. Competencies Developed through Socioscientific Issues (SSI)

To address the fourth research question, this study examined the types of competencies developed across the 53 selected articles on socioscientific issues (SSI) in science education. The analysis focused on three major domains—cognitive, epistemic, and affective—based on a deductively developed coding scheme aligned with the research questions. As multiple coding was applied, each article could contribute to more than one competency category. The detailed distribution is presented in Table 5.

Tabel 5. Distribution of Competencies Developed in SSI Studies (Multiple Coding Allowed)

Category	Sub-category	Number of Articles	Percentage (%)
Cognitive	Conceptual Understanding	18	33.96
	Scientific Literacy	15	28.30
Epistemic	Nature of Science (NOS)	10	18.87
	Evaluation of Evidence	12	22.64
	Scientific Reasoning	14	26.42
Affective	Attitudes toward SSI	16	30.19
	Values and Ethics	17	32.08
	Social Awareness & Responsibility	13	24.53

Note: Percentages are calculated based on the total number of articles (N = 53). Since multiple coding was applied, one article may contribute to more than one category; therefore, the total percentage exceeds 100%.

Cognitive Competencies

The findings show that SSI-based learning significantly contributes to the development of cognitive competencies, particularly in terms of conceptual understanding (33.96%) and scientific literacy (28.30%). Many studies emphasize how SSI contexts help students connect scientific concepts with real-world issues, thereby enhancing meaningful learning.

For example, research by Baltikian et al (2025) demonstrates the relationship between scientific literacy and students' attitudes toward climate change, while Smit et al (2025) highlight improvements in students' understanding and interest in science through SSI-based instruction. These findings suggest that SSI serves as an effective context for bridging theoretical knowledge and practical application.

Epistemic Competencies

Epistemic competencies represent a central dimension in SSI research, particularly in fostering students' understanding of how scientific knowledge is constructed and evaluated. The results indicate that scientific reasoning (26.42%) and evaluation of evidence (22.64%) are the most frequently addressed epistemic aspects.

Studies such as those by Garrecht et al (2023) and Dawson (2024) emphasize students' ability to construct arguments, assess evidence, and justify decisions in SSI contexts. Additionally, Nature of Science (NOS) (18.87%) is also explored, particularly in relation to understanding uncertainty, bias, and the role of scientific knowledge in society, as seen in the work of Şen & Öztuna Kaplan (2025). These findings reinforce the role of SSI as a powerful approach for developing higher-order thinking skills and epistemic awareness.

Affective Competencies

The affective domain is also strongly represented in SSI research, particularly in the development of values and ethics (32.08%) and attitudes toward SSI (30.19%). SSI inherently involves moral and ethical considerations, making it an effective approach for fostering students' value-based reasoning. For instance, studies by Tuncay-Yüksel

et al (2023) and Leung & Cheng (2023) explore how students develop moral reasoning and emotional engagement when dealing with socioscientific dilemmas.

In addition, social awareness and responsibility (24.53%) emerge as important outcomes, particularly in studies addressing environmental and sustainability issues. Research by Christodoulou & Grace (2025) highlights the development of environmental citizenship through SSI-based learning.

Overall, the results indicate that SSI-based learning supports a holistic development of competencies, integrating cognitive, epistemic, and affective domains. Among these, cognitive and affective competencies appear slightly more dominant, while epistemic competencies serve as a critical bridge connecting knowledge and values.

This pattern suggests that SSI is not only effective in enhancing students' understanding of scientific concepts but also plays a crucial role dalam membentuk cara berpikir ilmiah dan kesadaran sosial. However, the variation in emphasis across studies also indicates the need for more balanced integration of all competency domains in future research and practice.

RQ5. Research Gaps in Socioscientific Issues (SSI) Studies

Thematic Gaps in SSI Research

The analysis reveals that SSI research is still concentrated within a relatively narrow range of topics. A significant proportion of the 53 analyzed articles focus on environmental issues, particularly climate change, sustainability, and public health. While these themes are highly relevant and globally significant, this concentration indicates a lack of thematic diversity within SSI research.

Several important socioscientific domains remain underrepresented, including biotechnology ethics, artificial intelligence, energy transitions, and emerging technological risks. This imbalance suggests that current research has not fully captured the breadth of socioscientific challenges faced in contemporary society. Expanding thematic coverage is therefore essential to ensure that SSI-based education reflects the evolving landscape of science–society interactions.

Gaps in Research Focus and Variables

In terms of research focus, the findings indicate a strong emphasis on argumentation skills, scientific literacy, and students' attitudes. While these are important components of socioscientific competence, other critical dimensions receive comparatively less attention.

Specifically, constructs such as ethical decision-making, moral reasoning frameworks, and students' ability to navigate uncertainty are less frequently explored. Additionally, limited attention is given to long-term impacts, such as behavioral change and sustained civic engagement. This suggests that SSI research tends to prioritize immediate and measurable learning outcomes rather than more complex and longitudinal aspects of competency development.

Methodological Gaps

The methodological distribution of the analyzed studies also reveals notable limitations. Although qualitative approaches dominate the field, often providing rich and in-depth insights, there is a relative scarcity of large-scale quantitative and mixed-methods studies.

Furthermore, longitudinal research designs are rarely employed, limiting the ability to assess the long-term effectiveness of SSI-based interventions. The lack of methodological diversity reduces the generalizability and robustness of findings, indicating the need for more varied and rigorous research designs in future studies.

Contextual Gaps in Educational Levels

A clear imbalance is also evident in terms of educational contexts. Most SSI studies are conducted at the secondary school and higher education levels, while research at the primary school level remains limited.

This gap is particularly significant given the potential of SSI to foster early development of critical thinking, ethical awareness, and social responsibility. The limited number of studies focusing on younger learners suggests that the integration of SSI in primary education is still underexplored and requires further attention.

In addition, research on teacher professional development, especially in diverse cultural and institutional contexts, remains insufficient. This limits understanding of how educators can effectively implement SSI-based instruction across different educational settings.

Gaps in Technology Integration

Another important gap identified in this study relates to the integration of technology in SSI-based learning. While some recent studies address issues such as misinformation, digital literacy, and online scientific communication, the overall incorporation of advanced technologies remains limited.

Emerging tools such as artificial intelligence, virtual laboratories, simulations, and data-driven inquiry have not been widely integrated into SSI pedagogical frameworks. Considering the increasing role of digital environments in shaping socioscientific discourse, this gap represents a critical opportunity for future research and innovation.

Implications for Future Research

The identified gaps suggest that, although SSI research has made significant progress, it has not yet achieved a comprehensive and balanced coverage across themes, methods, and contexts. Future research should aim to diversify thematic areas, incorporate more robust and varied methodological approaches, and expand the implementation of SSI across different educational levels.

Moreover, greater attention should be given to integrating technology and addressing complex competencies such as ethical reasoning, decision-making under uncertainty, and long-term civic engagement. Addressing these gaps will be essential to strengthen the role of SSI as a transformative framework in science education.

CONCLUSION

This study provides a comprehensive overview of socioscientific issues (SSI) research in science education through a systematic literature review of 53 articles published in Q1 international journals between 2021 and 2025. The findings indicate a notable increase in SSI-related publications within the selected corpus, reflecting the growing recognition of SSI as a critical approach for addressing complex global challenges in science education.

The analysis shows that SSI research employs diverse methodological approaches, with a predominance of qualitative studies conducted at the secondary and higher

education levels. Thematically, research is largely concentrated on environmental and health-related issues, while pedagogical approaches such as argumentation, inquiry, and discussion are widely implemented. Moreover, SSI-based learning contributes to the development of multidimensional competencies across the cognitive, epistemic, and affective domains, supporting a more holistic conception of scientific literacy.

Despite these contributions, several gaps remain, including limited thematic diversity, underrepresentation of primary education contexts, insufficient integration of emerging technologies, and a lack of large-scale, longitudinal research designs. Certain competencies, such as ethical decision-making and sustained civic engagement, also remain underexplored.

In terms of implications, this study highlights the importance of integrating SSI more systematically across different educational levels, particularly in primary education, and expanding the use of innovative pedagogical approaches supported by digital technologies. For researchers, the findings emphasize the need to adopt more diverse and rigorous methodological designs to strengthen the evidence base of SSI studies.

This study is subject to several limitations. First, it is based on a bounded corpus of selected Scopus Q1 journals, which may limit the generalizability of the findings. Second, including only open-access articles may introduce corpus bias. Third, no formal quality appraisal of individual studies was conducted, which may affect the interpretation of methodological robustness.

Based on these findings, future research is recommended to expand thematic coverage, include broader educational contexts, integrate technology-enhanced learning, and employ a wider range of research designs, including longitudinal and large-scale studies. Such efforts are essential to strengthen further the role of SSI in developing scientifically literate and socially responsible citizens.

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