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The Role of Socioscientific Issues (SSI) in Natural of Science (NOS) Learning: A Systematic Literature Review

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Abstract: This study analyzes the role of socioscientific issues (SSI) in improving learners' competence in learning the nature of science (NOS) based on articles in SCOPUS-indexed journals. This systematic review used the PRISMA framework to classify the pedagogical aspects of SSI in science education. Of the initial 717 articles, 53 were selected based on inclusion and exclusion criteria. Results showed that SSI-based NOS learning can develop competencies such as argumentation, critical thinking, collaboration, communication, and conceptual understanding. Examples of SSI integration include climate change, biotechnology, biodiversity, waste management, and chemical engineering. Its implementation involves inquiry, problem, and model-based strategies, with methods of discussion, debate, digital resources, and role-play. This review concludes that SSI provides a transformational approach to NOS learning by enhancing learners' cognitive and interpersonal competencies, making it a promising framework for future educational practice.

Keywords: Natural of science; Socioscientific issues; Student competence

Introduction

Socioscientific issues (SSI) represent a conceptual framework that has gained significant attention in the field of science education as a means of fostering scientific literacy. This framework is employed by educators and researchers to bridge the gap between theoretical understanding, empirical research, and practical classroom applications. As a result, SSI can be viewed from various perspectives, each contributing a distinct interpretation of its purpose and scope. At its core, SSI seeks to engage students in complex real-world problems that are inherently interdisciplinary, drawing upon multiple facets of knowledge and skills, making it a valuable tool in advancing scientific literacy (Högström et al., 2024; Zeidler et al., 2019). The meaning and application of SSI can be challenging to fully grasp, primarily due to the diversity of its objectives. When viewed through a theoretical lens, SSI emphasizes the exploration of the fundamental nature of science and the role of scientific knowledge in shaping societal decisions. From a research-oriented perspective, SSI provides a rich context for examining how students develop higher-order cognitive skills such as argumentation, critical thinking, and reflective judgment. In practical terms, SSI offers a framework for teachers to create dynamic and engaging learning environments where students engage in dialogue, reason through moral and ethical dilemmas, and consider the broader implications of scientific advancements on society (Zeidler et al., 2019).

SSI integrates insights from a broad range of interconnected scholarly fields. In terms of epistemological development, SSI encourages students to reflect on the nature of scientific knowledge, the processes through which it is constructed, and the ways

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in which it interacts with societal values (Högström et al., 2024). Furthermore, SSI fosters sociomoral discourse, inviting students to examine the ethical dimensions of scientific issues and develop empathy for differing viewpoints. Emotional reasoning also plays a crucial role, as students are often asked to consider the emotional and human aspects of issues like climate change, biotechnology, and public health (Zeidler et al., 2019). Character education is another significant component of SSI, as it helps students cultivate a sense of responsibility and citizenship by addressing issues that directly impact their communities and the world at large. Through SSI, students can develop the ability to engage in thoughtful and respectful debate, express their values, and make informed decisions based on evidence and societal needs (Zeidler et al., 2019).

As a context within science education, Socioscientific Issues (SSI) serve as a vital bridge between scientific knowledge and societal concerns, integrating real-world issues into the science curriculum (Herman et al., 2019). These issues often arise from the application of scientific advancements to tackle a wide range of challenges that are not only scientific but also social, moral, economic, regulatory, and political in nature. For instance, issues such as climate change, biotechnology, and the ethical implications of emerging technologies involve complex questions that intertwine scientific understanding with societal values and decisions (Falah et al., 2024). This context allows students to see science as a tool not just for understanding the natural world, but for addressing pressing issues that affect their communities and the global society. Unlike traditional science education, which often prioritizes content-driven learning and a focus on factual knowledge and technical skills, SSI pedagogy emphasizes the practical application of scientific principles in solving real-world problems (Hodson, 2014). Consequently, SSI instruction adopts methods such as inquiry, argumentation, and role-playing to engage with authentic societal practices, contrasting with traditional scientific practices like laboratory experiments and modeling (Högström et al., 2024; Zeidler et al., 2009; Zohar & Nemet, 2002).

Research on socioscientific issues (SSI) has made significant contributions to science education by providing an effective platform for exploring scientifically explainable problems. SSI not only influences students' attitudes toward societal challenges but also cultivates empathy and moral reasoning through collaborative engagement (Lee et al., 2020). Collaborative discussions enhance moral reasoning across cultures, encouraging the adoption of values like honesty, empathy, and trust. Moreover, SSI lays a strong foundation for students to understand science and the Nature of Science (NOS), fostering interest, motivation, argumentation, and critical thinking (Dawson, 2015; Falah et al., 2024). Through real-world applications, SSI helps learners grasp and apply scientific explanations and NOS, linking their attitudes to science learning. It also has the potential to enhance Emotional Competence (EC), which supports students' scientific understanding and character development (Gao et al., 2019; Herman et al., 2019; Xiao & Sandoval, 2017). Studies have shown that structured engagement with SSIs improves students' reflective judgment, reasoning, contextualized content knowledge, and understanding of NOS while also promoting character development and global citizenship values (Eastwood et al., 2012; Lee et al., 2020; Sadler et al., 2007; Zeidler et al., 2009; Zeidler et al., 2002). Together, these outcomes embody the concept of functional scientific literacy within the SSI framework.

Students with a positive attitude toward science tend to have a deeper understanding of scientific concepts. Likewise, those with a favorable disposition toward science are more inclined to develop critical thinking skills and actively participate in the learning process. SSI plays a vital role in science education by promoting positive attitudes, empathy, moral reasoning, critical thinking, and learning within real-world contexts. Current SSI research trends offer valuable insights for advancing both practical implementation and theoretical frameworks (Chen & Xiao, 2021). As an innovative learning approach, SSI incorporates moral considerations into addressing social issues. By integrating social viewpoints with scientific reasoning, it equips students with reflective problem-solving skills. Nevertheless, challenges persist, such as difficulties students face in articulating environmental issues using reasoning and the limitations educators experience in implementing socially just learning practices due to curriculum constraints that prioritize textual resources. While SSI strategies have proven effective in enhancing critical thinking, questioning skills, cognitive outcomes, and environmental reflection, their primary focus often remains on building learning competence (Tsai, 2018). Therefore, it is essential to address key aspects of SSI, such as its impact on developing student competencies, its integration into Nature of Science (NOS) content, and the design of effective learning models and methods to support the SSI approach.

Method

This systematic review followed the PRISMA framework as a guiding methodology, aiming to classify the pedagogical aspects of SSI within the context of teaching and learning in science education. By adopting an inclusive approach, the review encompassed a broad spectrum of research interests, study designs, and theoretical viewpoints. This approach allowed for the integration of a variety of studies, offering numerous examples of the teaching objectives, topics, models, and methods used in SSI-based education. Additionally, the review analyzed the frequency of SSI-related competencies, content areas, and instructional strategies highlighted in the literature on science education.

A literature search process was carried out to collect information on SSI, ensuring that the search was broad, valid, and comprehensive. This was achieved by utilizing various academic databases relevant to the study, including Scopus. The selection of databases was guided by the focus on educational research as well as social and psychological sciences. The search process followed four steps. First, general SSI-related terms, such as socioscientific issues and SSI, were used across all databases. Second, more specific terms relevant to science education were employed in the Scopus database, including students, socioscientific issues in natural science, and SSI in education. Third, searches incorporated terms connected to social issues like learning and skills, focusing on the school context and informed decision-making. To qualify for inclusion, the search terms had to appear in the title, abstract, or keywords of the publication with Scopus indexed article publication type Q1 to Q4. This literature search was conducted during September and October 2024.

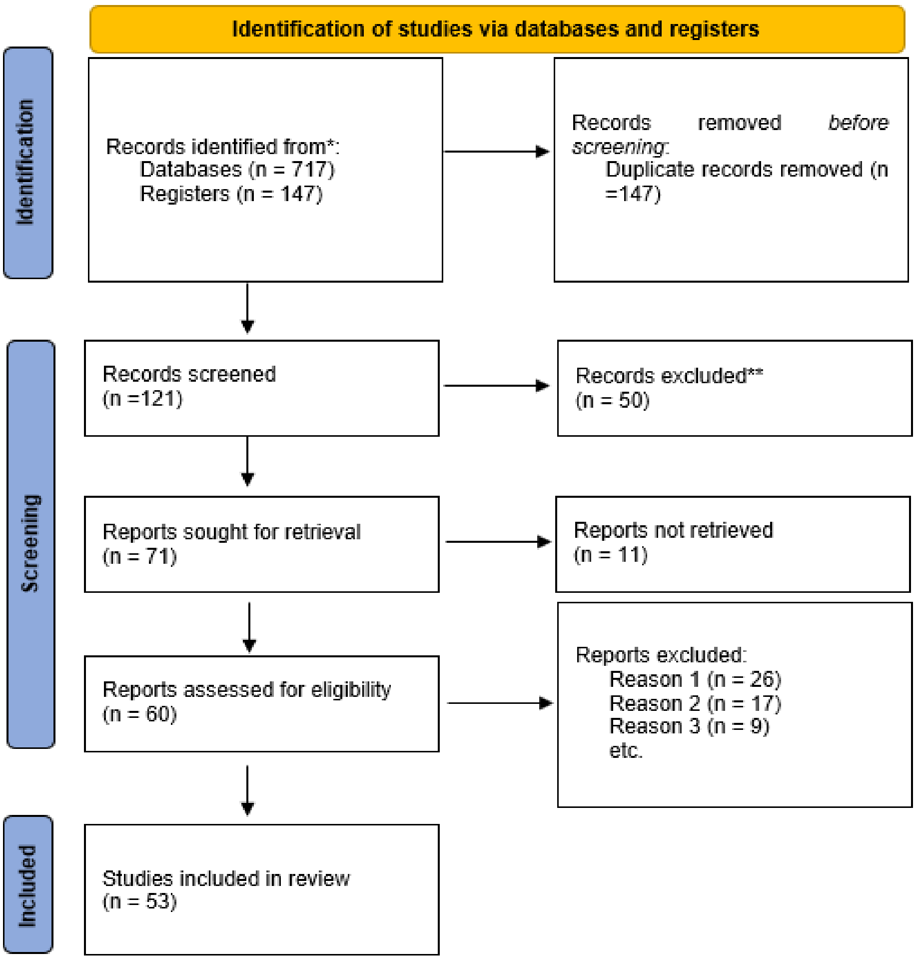

Figure 1. Prism of Systematic Literature Review

Result and Discussion

Socioscientific issues was originally popularized by Zeidler and his colleagues around 1990. Since then, many studies have investigated this innovative teaching model. Figure 2 provides an overview of the distribution of articles reviewed in Socioscientific Issues which was created using R software, from 1999 to December 2024. The years 2023 and 2024 have the highest publication of socioscientific issues related articles. This surge may be due to technological developments and climate change. Both are interrelated issues that form complex challenges for the global community. The socioscientific issues approach offers a useful framework to address these challenges by engaging multiple perspectives and encouraging collaboration to find equitable and sustainable solutions.

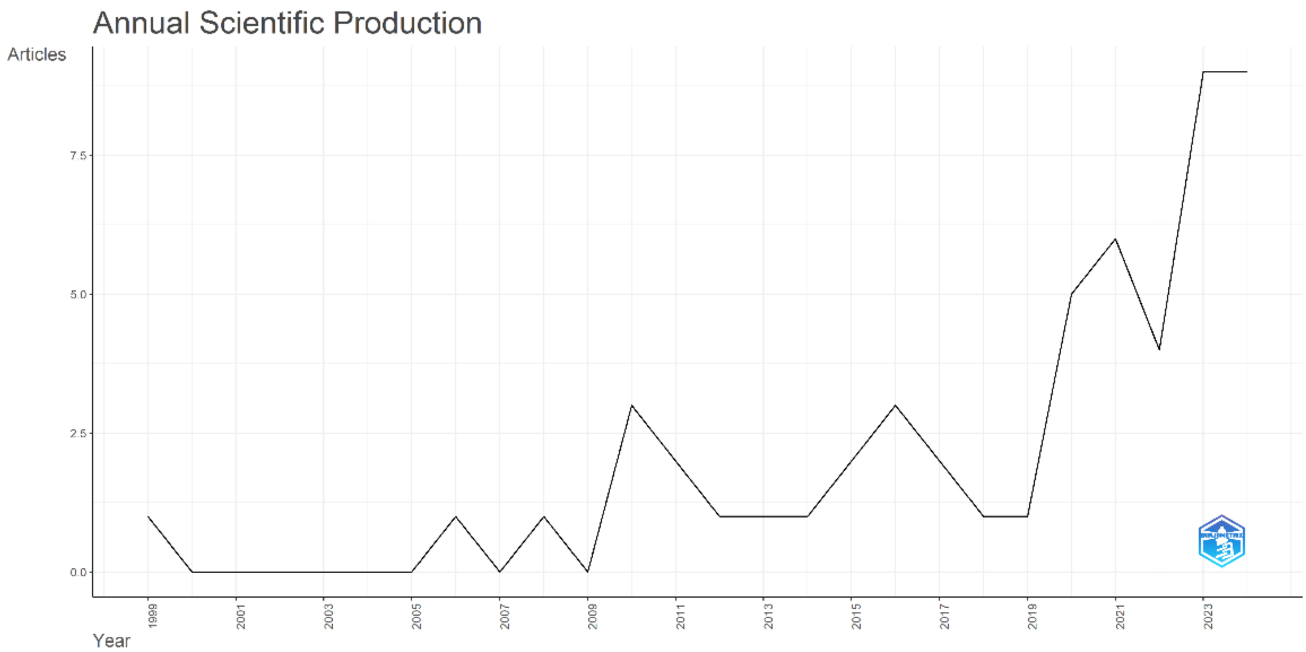

Figure 2. Annual scientific production

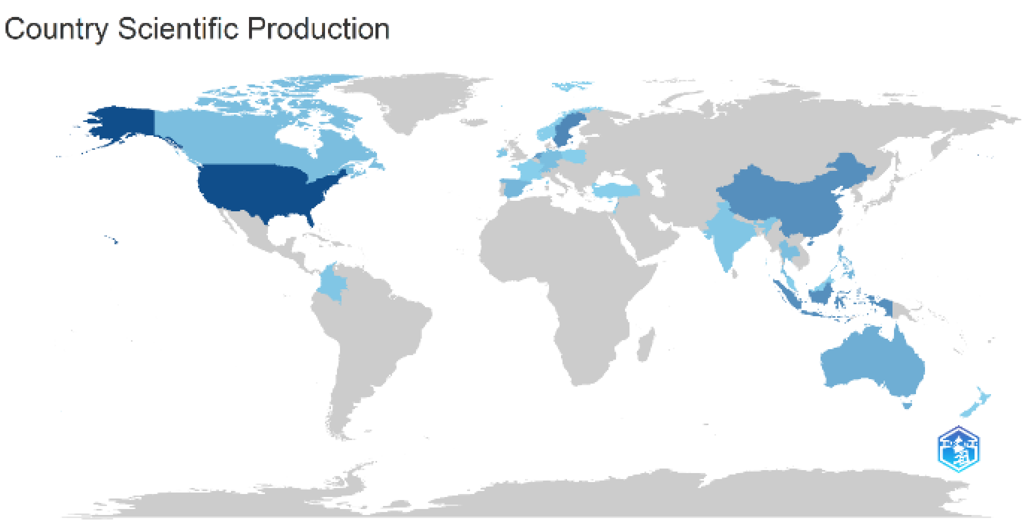

Figure 3. Country scientific production by R

The research locations of the articles in this systematic review are diverse. Of the 53 articles examined, they came from 24 different countries. The distribution map of the articles provides an interesting insight into the interest of researchers from different countries in Socioscientific Issues (Figure 3). This fuelled a global discussion on their effectiveness and implementation in diverse educational contexts. USA stands out with 18 articles, Sweden 10, then China and Indonesia 9 articles each, Netherlands 7, Australia 5, Philippines and Spain 4. A systematic literature review of the articles showed that the studies were conducted with different levels of participants. Analysis of the data showed that most of these studies focussed on secondary school students.

The Role of SSIs in Student Competence

Table 1 highlights various student competencies emphasized in SSI learning, with the most prominent being argumentation and understanding of the Nature of Science (NOS), each accounting for 24% (six articles). This is followed by decision-making, which represents 20% (five articles), while other competencies are below 20%. Empowering students to make informed decisions when faced with complex socioscientific issues aligns with the overarching goal of fostering responsible and informed citizens e.g., Chowdhury et al. (2020) and Zeidler (2014). Competencies such as argumentation and communication frequently support decision-making processes and are central objectives in SSI teaching. Strong communication and reasoning skills are essential tools that enable students to articulate their opinions, critically evaluate information, and develop intellectual resilience. The findings indicate that most SSI pedagogical approaches focus on cultivating higher-order thinking skills, including critical thinking, argumentation, and moral reasoning, which empower students to make informed decisions. This aligns with how SSI is characterized in the literature. However, as noted by Espeja & Couso (2020). SSI is often not effectively integrated into science teaching practices. Despite its recognized importance over the past decades, the implementation of SSI remains insufficient (Chen & Xiao, 2021; Espeja & Couso, 2020). Competencies like decision-making, argumentation, and communication represent progressive learning objectives that differ from the traditional focus of science education, which tends to prioritize content knowledge (Hodson, 2014).

Table 1. Student competence in SSI

Students' skills	Authors (Year)	Number of articles	%
Making decision	Zeidler (2014), Chowdhury et al. (2020), Karpudewan & Roth (2018), Lee et al. (2020), Sagmeister et al. (2021)	5	20
Reasoning scientific knowledge	Chen & Liu (2018), Lin et al. (2020)	2	8
Argumentation	Siska et al. (2019), Dawson (2015), Zohar & Nemet (2002), Capkinoglu et al. (2019), Dawson & Venville (2021), Tsai (2018)	6	24
Communication	Lee et al. (2016), Byhring & Knain (2016), Feierabend & Eilks (2010)	3	12
Understanding NOS	Sadler (2004), Karisan & Zeidler (2016), Longoni & Cian (2020), Eastwood et al. (2012), Solli et al. (2019), Herman et al. (2019)	6	24
Students' action skills, participation in democratic processes, and scientific literacy	Fahrizal & Badrun (2022), Kinslow et al. (2018), Chen & Liu (2018)	3	12

A number of studies have highlighted the positive effects of SSI contexts on students' argumentation skills (Dori et al., 2003; Pedretti, 1999; Sadler, 2009; Tal & Hochberg, 2003; Tal & Kedmi, 2006; Walker & Zeidler, 2007). However, some research has also pointed out challenges in improving students' argumentation abilities, which are often encountered in broader discussions on argumentation (Albe, 2007; Harris & Ratcliffe, 2005; Kortland, 1996). Additionally, studies have shown that SSI contexts foster creativity, with students frequently demonstrating innovative thinking (Yager et al., 2006) or experiencing significant improvements in creativity (Lee & Erdogan, 2007). Furthermore, SSI-based teaching has been found to encourage epistemological development, particularly in the area of reflective judgment (Zeidler et al., 2009). When it comes to the acquisition of scientific knowledge, most research suggests that SSI learning environments are highly effective in enhancing students' conceptual understanding (Klosterman & Sadler, 2010; Sadler et al., 2007; Yager et al., 2006; Zeidler et al., 2009).

Learning Topics in SSI

Tables 2 and 3 reveal two key thematic areas in SSI (Socioscientific Issues) teaching: environment and sustainable development and health and technology. In Table 2, which addresses SSI content related to technology and health, the most frequently emphasized area is biotechnology and medicine, accounting for 63% (five articles). Similarly, in Table 3, which focuses on SSI content within the environment and sustainable development, climate change is the most frequently highlighted topic, representing 41% (seven articles). The diversity of these topics underscores the multifaceted nature of SSI, where scientific principles intersect with societal challenges, promoting a comprehensive understanding of science's impact on daily life. The health and technology theme encompasses topics such as biotechnology and medicine, food, materials chemistry and engineering, and radiation. These subjects often introduce ethical dilemmas and considerations of risk, particularly in the context of human well-being. Sadler & Zeidler (2005) suggest that SSI teaching has its roots in the biotechnology domain, a notion that remains relevant today. Recent reviews, such as those by Çalık & Sözbilir (2014) on chemistry education, confirm that the trend of examining the impact of chemicals particularly in areas like food and medicine continues to be significant.

Table 2. SSI topics related to technology and health

SSI Topics	Authors	Number of articles	%
Biotechnology and medicine	Nordqvist & Aronsson (2019), Çalık & Sözbilir (2014), Sagmeister et al. (2021), Berne (2014), Schenk et al. (2021)	5	63
Chemical and materials engineering	Dawson (2015); Hernández-Ramos et al. (2021)	2	25
Radiation	Schenk et al. (2021)	1	13

Table 3. SSI relates to the environment and sustainable development

SSI topics	Authors	Number of articles	%
Climate changes	Dawson (2015), Okur & Seyhan (2021), Feierabend & Eilks (2010), Karpudewan & Roth (2018), Kurup et al. (2021), Rudd et al. (2020), Zangori et al. (2015)	7	41
Biodiversity	Hernández-Ramos et al. (2021), Meisert & Jafari (2021), Freitas et al. (2023)	3	18
Waste control	Hernández-Ramos et al. (2021)	1	6
Management Energy and resources	Birmingham & Barton (2013), Atabey & Topcu (2020), Chen & Liu (2018)	3	18
Environmental Pollution	Chowdhury et al. (2020), Byhring & Knain (2016), Çalık & Sözbilir (2014)	3	18

Socioscientific issue (SSI) topics are increasingly recognized as being deeply embedded within societal contexts, engaging with local, national, and global concerns while encouraging students to critically engage with complex issues of values, ethics, and morals in these various settings, as emphasized in previous reviews e.g., Sadler & Zeidler (2005). In environmental issues, some of the most prominent and pressing topics include climate change, the loss of biodiversity, environmental pollution, and resource management—challenges that demand a deep understanding from students and prompt them to take meaningful action. The findings of this analysis reflect and build upon earlier reviews, which have identified similar dominant topics through various perspectives. For instance, Hernández-Ramos et al. (2021), focused on technology-enhanced SSI issues, while Schenk et al. (2021) delved into the concept of risk as a central theme in SSI research. By adopting a broader lens, this comprehensive systematic review offers a more expansive and nuanced mapping of the field. Furthermore, a review by Çalık & Sözbilir (2014) of SSI studies in chemistry education between 2008 and 2020 indicated that most of the research centered on issues like chemical pollution and the use of fossil fuels. Interestingly, the relatively low attention given to radiation-related issues, is consistent with the findings of Schenk et al. (2021) may reflect its reduced prominence in media and societal discourse compared to two decades ago.

SSI Learning Model

The SSI teaching model holds particular significance as it situates learning within societal contexts rather than the confines of a scientific laboratory (Sadler, 2009). Furthermore, a systematic review by Hernández-Ramos et al. (2021) on the effects of incorporating SSI in problem-based learning suggests that the positive outcomes on student competence and motivation may primarily result from the teaching methods employed rather than the course content itself. This underscores the importance of the SSI learning model. Presley et al. (2013), in their development of an SSI teaching framework, identified three key components, two of which pertain to instructional methods and approaches. First, students should actively engage in the learning process. Second, the teacher's role should shift to that of a facilitator. Third, the classroom environment should foster collaboration and mutual respect. A systematic review of related studies identifies three main categories of learning models employed to teach SSI in classrooms. According to Table 4, the most commonly used approaches are inquiry-based learning (44%, four articles) and methods such as problem-based, context-based, and case-based learning, which also account for 44% (four articles). Lastly, model-based learning, which employs physical or conceptual models to address scientific concepts and social issues, represents 11% (one article).

Table 4. The SSI learning models

Models	Authors	Number of articles	%
Inquiry learning model	Alcaraz-Dominguez & Barajas (2021), Maass et al. (2022), Georgiou & Kyza (2023), McKnight et al. (2021)	4	45
Problem based, context based, case based	Wiyarsi et al. (2021), Chowdhury et al. (2022), Varis et al. (2018), Aisy et al. (2024)	4	45
Model based	Erumit & Yuksel (2023)	1	11

Socioscientific issues are often associated with inquiry-based learning (IBL), an instructional approach that fosters active exploration and critical questioning (Alcaraz-Dominguez & Barajas, 2021). A more specific form of IBL, known as socio-scientific inquiry-based learning (SSIBL), focuses on addressing socioscientific problems through inquiry. This scoping review draws attention to recent research that employs inquiry-based learning as a teaching framework. For instance, Georgiou & Kyza (2023), Maass et al. (2022), and McKnight et al. (2021) developed inquiry-based resources designed to teach genetics and genomics within the senior biology curriculum in Australia. These resources aimed to enhance teachers' knowledge and confidence in delivering these complex topics to students aged 16-18. The learning models discussed in the literature review are closely aligned with problem-based, context-based, and case-based learning approaches. These models immerse students in real-world situations, encouraging them to assume the role of problem solvers. As highlighted by Alcaraz-Dominguez & Barajas (2021), such approaches utilize relevant, applied problems to teach STEM subjects, engaging students in ways that make the learning experience more meaningful. Context-based science education, which addresses the complexities of real-world issues, is intrinsically linked to the socio-scientific problem approach. Three recent studies illustrate this alignment.

The third learning model discussed is model-based learning, which incorporates the use of demonstration and physical dynamic models in educational settings. These models facilitate interactive learning, enabling students to make predictions, conduct tests, observe outcomes, and draw conclusions about scientific phenomena (Erumit & Yuksel, 2023). One such example is found in the work of Maass et al. (2022), who explored the application of mathematical modeling to address real-world problems. Their research indicated that mathematical modeling enhances student engagement with mathematics, deepens their understanding of its practical uses, and promotes mathematical literacy. The study also revealed that engaging in modeling activities improves students' ability to tackle complex, open-ended problems—those without clear-cut solutions and requiring the consideration of multiple factors.

SSI Learning Methods

The literature summarized in Table 5 highlights various pedagogical strategies that prioritize student engagement, dialogue, and active participation (Chen & Xiao, 2021; Chowdhury et al., 2020; Presley et al., 2013). Among these strategies, group discussion is the most frequently employed, accounting for 56% (five articles), followed by role-play at 22% (two articles), and both debate and digital resources at 11% each (one article each). Group discussions emphasize the collaborative nature of SSI learning, allowing students to explore issues collectively, which aligns with findings from previous reviews on effective teaching methods (Presley et al., 2013) and and active learning practices (Chen & Xiao, 2021). While debates and role-playing are closely related to group discussions due to their focus on communication and reasoning, they differ in structure and application. Debates involve students adopting specific roles and adhering to defined rules and viewpoints, providing a structured framework to engage with complex topics. Role-playing, on the other hand, fosters empathy and a deeper understanding of multiple perspectives by allowing students to embody different roles. This approach immerses students in real-world issues, enabling them to grasp the complexities of diverse viewpoints. Despite their benefits, debates and role-playing are far less common than group discussions in SSI teaching practices.

Table 5. SSI learning methods

Methods	Authors	Number of articles	%
Discussions	Chen & Xiao (2021), Chowdhury et al. (2020), Bossér & Lindahl (2020), Raveendran et al. (2021), Karakaş (2022)	5	56
Debate	Agell et al. (2014)	1	11
Role play	Espeja & Couso (2020), Zeidler et al. (2009)	2	22
Digital resources	Hansson et al. (2011)	1	11

In study by Chen & Xiao (2021), identified four key learning activities frequently used by educators in teaching Socioscientific Issues (SSI). The most commonly employed method was class discussions, which foster collaborative engagement and critical thinking. The second most widely used approach was group work or problem-based learning, often supplemented by activities such as role-playing, where students are encouraged to explore and adopt different viewpoints and interests related to contentious issues. The third teaching strategy identified was argumentation-driven instruction, which is specifically designed to promote critical thinking by encouraging students to defend their positions through structured arguments. The fourth approach highlighted in the study was the use of questioning techniques, where teachers pose thought-provoking questions that challenge students' positions and stimulate deeper reflection on various controversial issues. These pedagogical approaches, while emphasized in Chen & Xiao (2021) research, are also seen in other studies, though not always with the same level of structure. For example, Zeidler in Bencze et al. (2020) described SSI pedagogy as involving discussions, debates, and the defense of different perspectives, informed by both scientific and moral viewpoints. These elements are also aligned with the defining characteristics of SSI, as noted by Chowdhury et al. (2020).

A common thread throughout these studies is the emphasis on fostering active student participation, which requires students to engage in communication and reasoning—both formally through argumentation and informally through moral reasoning. This focus on active engagement has led to the development of the concept of "socio-scientific reasoning" to capture the core activities in SSI classrooms (Sadler et al., 2007). Socioscientific reasoning involves understanding the inherent complexity of SSIs, considering multiple perspectives, recognizing that these issues are ongoing and subject to change, and maintaining a critical stance toward potentially biased information. Furthermore, Simonneaux & Simonneaux (2009) pointed out that a crucial aspect of socioscientific reasoning is the ability to identify risks and uncertainties while also expressing values, further enriching the approach to teaching SSIs.

Conclusion

This systematic review highlights the diverse scope of SSI (Socio-Scientific Issues) learning studies in science education, with a focus on student competencies, instructional models, and teaching strategies. The findings emphasize the significant yet underutilized potential of SSI in bridging environmental, social, technological, and scientific literacy. Despite its theoretical robustness, the practical application of SSI in classrooms remains a challenge, with progress hindered by the shift from traditional science teaching methods to the more integrative and dynamic approaches SSI demands. The review identifies a persistent gap between theoretical research and real-world educational practices, underscoring the need for targeted strategies to address this divide. SSI has demonstrated a measurable positive impact on specific student competencies, particularly critical thinking, understanding the Nature of Science (NOS), argumentation, communication, and decision-making. To maximize its effectiveness, SSI can be integrated into NOS education through relevant topics such as climate change, biotechnology, and environmental pollution, employing interactive methods like problem-based learning, inquiry-based learning, debates, and digital tools. These findings underscore the necessity for more focused research on how SSI can be systematically implemented in classrooms, paving the way for evidence-based policies and practices that align with modern educational needs.

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Author Contributions
For this article, there are 4 authors. First, A.M.B.N.: contributed to the conceptualization and writing-original draft preparation. Secondly, M.S.P.: methodology, software, and formal analysis. Third, R.R.I.: contributed to finding sources or references and data curation. Finally, H.K.: as a lecturer as well as directed us in making articles and reviews.

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The authors declare no conflict of interest with the research, writing, or publication of this article. All results and opinions presented are the independent views of the authors and are not influenced by institutional affiliations, sponsors, or other parties.

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