Understanding how socio-scientific issues shape science education worldwide: A systematic review

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Abstract. This systematic review examines how socio-scientific issues (SSI) are implemented in science education across different countries between 2015 and 2024. Using the PRISMA protocol, a comprehensive search was conducted in Scopus and ERIC, yielding 1,243 unique records, of which 31 met all eligibility criteria. The reviewed studies represent sixteen countries and show that SSI is used primarily as a flexible learning context rather than a fixed instructional method. Environmental, health, energy, biotechnology, and culturally specific issues are commonly integrated to connect science learning with real-world societal challenges. SSI supports diverse pedagogical approaches, including context-based learning, dialogic engagement, and project-oriented activities. Across these studies, SSI enhances key student competencies such as argumentation, decision-making, critical and higher-order thinking, scientific literacy, environmental citizenship, engagement, and future thinking. The review highlights growing global interest in SSI and underscores the need for stronger assessment tools, including those designed for digital SSI, as well as greater teacher support to optimize its implementation.
Keywords. socio-scientific issues, science teaching, mapping, student competencies, context-based learning

1 Introduction

Extensive research has revealed that science education, especially in fields such as physics, chemistry, and biology, remains challenged by persistent patterns of student disengagement and diminishing interest [1-2]. In addition to this, scholars consistently report that students tend to perceive science as abstract, difficult, and disconnected from their everyday experiences [3]. This perceived lack of relevance reduces students' motivation to engage meaningfully in scientific inquiry or to appreciate the importance of scientific knowledge [4]. Several scholars have emphasized that science learning frequently does not inspire students to participate in the processes of doing science and learning science in ways that are contextually meaningful [5-6].

A wider concern arises from the observation that students tend to view science education as having limited relevance to personal, societal, and global challenges [7]. Such a disconnect has encouraged the development of approaches that position science within authentic and meaningful contexts. The relevance model proposed by Stuckey et al. [8] highlights the importance of connecting scientific ideas to learners' personal needs, societal issues, and future aspirations. Within this model, socio-scientific issues (SSI) have received increasing attention as a pedagogical approach that can promote relevance, authenticity, and meaningful engagement [9-10].

SSI involve real-world problems that integrate scientific knowledge with ethical, social, environmental, economic, and political considerations [11]. These issues often involve contested viewpoints and require individuals to evaluate evidence, deliberate on alternative perspectives, and make informed decisions. Previous studies have reported that SSI can enhance students' scientific literacy [12], argumentation [13], critical thinking [14], decision-making [15], and environmental responsibility [16]. As global challenges such as climate change [17], biotechnology [18], pandemics [19], and sustainability [20] become more prominent, SSI have become an increasingly important component of contemporary science education.

Over the past decade, research on SSI has expanded across multiple regions including Asia, Europe, North America, South America, and Australia. However, despite the growing body of literature, existing reviews remain limited in scope. Earlier reviews such as Genisa et al. [21] provided valuable insights but covered a narrower time frame and a more restricted set of pedagogical orientations. Since then, SSI research has grown substantially, revealing a wider diversity of issue types, instructional models, and targeted student competencies. Recent studies also highlight innovative approaches such as culturally situated SSI [22], digital-based SSI learning [23], environmental citizenship frameworks [24], and competencies related to future thinking and scientific habits of mind [11].

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These developments indicate the need for an updated and comprehensive synthesis of SSI implementation at the global level. Such a review can reveal how countries have adopted and contextualized SSI, which pedagogical strategies dominate current practice, and which student competencies are prioritized in different educational contexts. Understanding these patterns is essential for guiding researchers, curriculum designers, and teachers who aim to strengthen the role of SSI in improving the quality and relevance of science education.

To address this need, the present study conducts a systematic literature review of empirical research on SSI implementation in science education published between 2016 and 2024. The review synthesizes evidence from sixty-two studies across sixteen countries to provide an updated map of global practices, conceptual orientations, and emerging directions in SSI pedagogy. The study is guided by the following research questions.

1. How has SSI implementation in science education been distributed across countries between 2015 and 2024?
2. How are different types of SSI and contextual themes employed in SSI-based science learning across various national settings?
3. How are instructional approaches and pedagogical orientations used to integrate SSI into science education?
4. How are challenges and future directions characterized in SSI research published from 2015 to 2024?

2 Method

This systematic review was conducted to examine the implementation of SSI within science education across different national contexts. The review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, ensuring transparency and rigor throughout the identification, screening, and selection procedures.

A comprehensive literature search was performed in October 2024 using two major research databases, Scopus and the Education Resources Information Center (ERIC). Scopus was selected due to its extensive multidisciplinary coverage and established quality control of indexed publications [25]. ERIC was included as a specialized database that provides curated and peer-reviewed educational research [26]. The search strategy employed combinations of controlled vocabulary and keyword terms related to SSI, science education, instructional implementation, and teaching strategies.

The initial search retrieved 1,158 documents from Scopus and 99 from ERIC. After the removal of 14 duplicate records, 1,243 documents were retained for further screening. The complete search queries applied in each database are presented in Table 1.

Eligibility criteria required the inclusion of peer-reviewed journal articles published between 2015 and 2024, written in English, and available in full text. Studies were excluded if they were conference proceedings, books, or systematic review articles, or if they were published prior to 2015 or not accessible in full. Articles meeting the inclusion criteria were subsequently assessed for relevance based on their empirical examination of SSI within science education.

Table 1. Queries used on searching process.

Database	Keywords search and other applied filters
Scopus	TITLE-ABS-KEY(("socio-scientific issues" OR "SSI" OR "socio-scientific context") AND ("science education" OR "science teaching" OR "science curriculum" OR "science literacy") AND ("implementation" OR "integration" OR "application" OR "teaching method" OR "instructional strategy"))
ERIC	("socio-scientific issues" OR "SSI" OR "socio-scientific context") AND ("science education" OR "science teaching" OR "science curriculum" OR "science literacy") AND ("implementation" OR "integration" OR "application" OR "teaching method" OR "instructional strategy")

Reference management and screening processes were facilitated using Zotero. The selection procedure consisted of sequential title screening, abstract screening, and full-text assessment. This process resulted in 53 eligible articles from Scopus, 46 from ERIC, yielding a total of 99 studies for detailed evaluation. Following full-text review, 68 studies were excluded due to insufficient relevance or failure to meet methodological criteria. Ultimately, 31 articles were included in the final analysis. The full selection process is depicted in Figure 1.

All included articles were coded and classified according to their relevance to SSI implementation in science education. To ensure the credibility and consistency of the coding process, the analysis underwent peer coding validation as well as expert review from a specialist in science education. This dual validation strengthened the reliability of category assignments and thematic interpretations. To illustrate the geographical spread of SSI research, a global distribution map was developed using Lucidchart software.

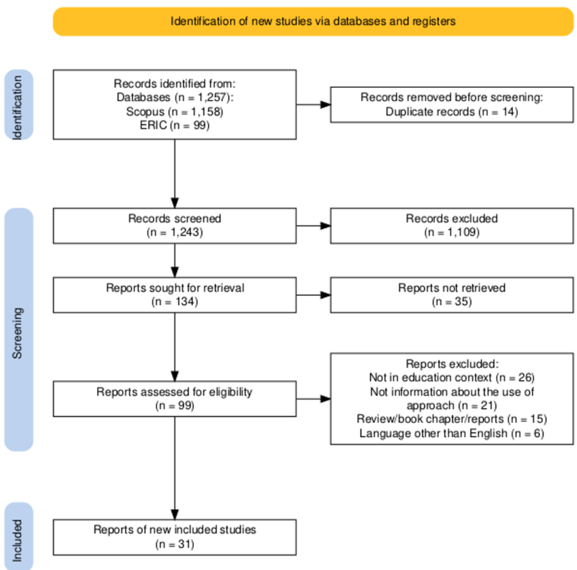

Fig. 1. PRISMA flow diagram.

3 Result and discussion

Over the past decade, research on SSI has grown rapidly and become a prominent theme in science education. Studies increasingly highlight the role of SSI in supporting scientific literacy [9], fostering authentic reasoning [27], strengthening decision-making [28], and improving student engagement with real-life contexts [29]. This expanding body of work spans various perspectives, including conceptual understanding, ethical reflection, socio-scientific reasoning, and the evaluation of learning outcomes. Overall, SSI has evolved into a flexible pedagogical framework that enables learners to think critically, use evidence, and participate in societal discussions involving science and technology.

This review contributes to this growing field by mapping the global distribution of SSI implementation from 2015 to 2024. The analysis identified studies from sixteen countries, each employing SSI themes that reflect local environmental, technological, cultural, or socio-political concerns. As shown in Figure 2, research is spread across North America, South America, Europe, Asia, and Australia, addressing issues such as environmental quality, energy use, biotechnology, public health, food safety, scientific habits of mind, and citizenship. This distribution underscores the rising global relevance of SSI and illustrates how national contexts shape the types of issues integrated into science classrooms.

To deepen this global overview, the following sections present a structured synthesis of publication trends, types of SSI domains, instructional approaches, and the challenges and future directions reported in the literature. This organization provides a comprehensive understanding of how SSI has influenced science education worldwide and how the field has evolved over the past decade.

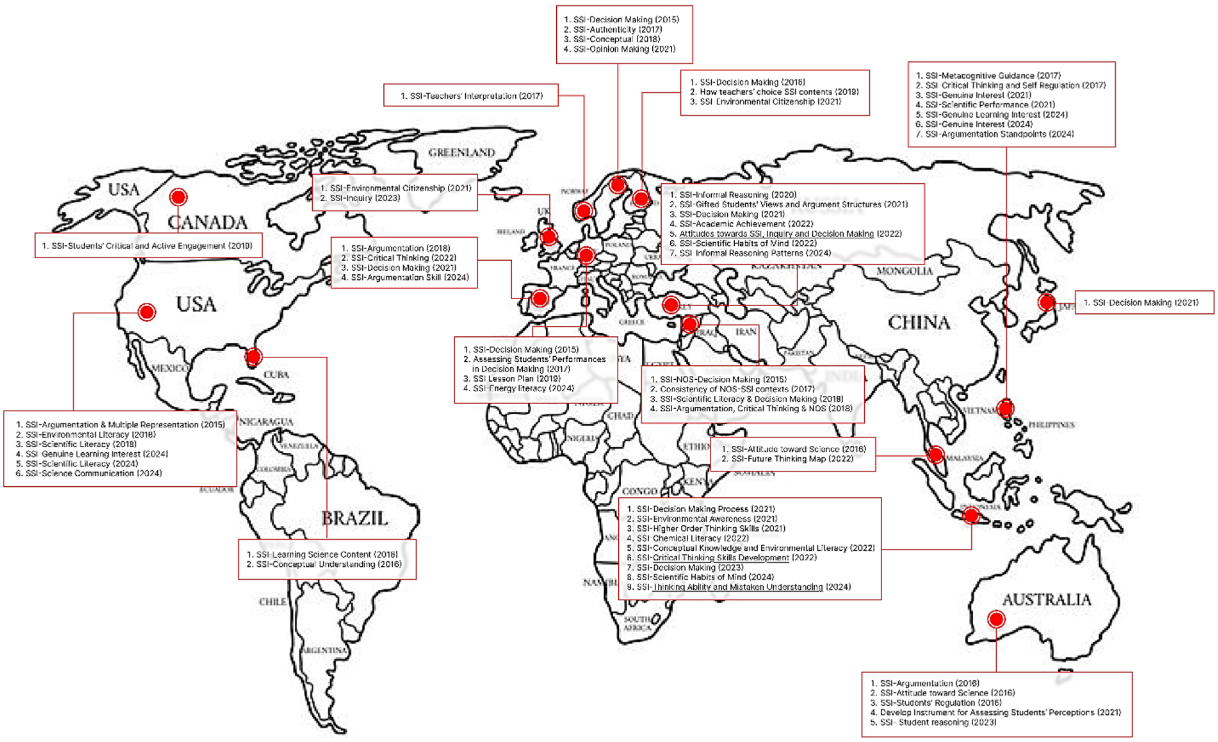

Fig. 2. Map of research distribution related to SSI across the world.

3.1 Global publication trends and research characteristics

The review of SSI-related publications from 2015 to 2024 reveals a clear and sustained expansion of research activity across the world. A total of 16 countries contributed empirical studies on the implementation of SSI in science education, with the most active regions including the United States, Spain, Turkey, Taiwan, Indonesia, Germany, and the United Kingdom. The distribution of studies, visualized in Figure 2, shows that SSI research has become increasingly global, extending beyond traditionally dominant Western contexts to include South America, Southeast Asia, and the Middle East. This widespread geographical coverage reflects the escalating relevance of SSI for addressing contemporary societal challenges that intersect with science, technology, environment, and ethics.

The publication trends suggest that SSI research is steadily increasing in both quantity and thematic diversity. Early studies (2015–2017) predominantly focused on core SSI constructs such as argumentation [13-14], decision-making [15, 17, 30-32], and socio-scientific reasoning [18, 33]. These foundational themes continue to appear prominently in countries like Spain, Turkey, Taiwan, and the United States. Over time, however, the field has broadened to encompass newer areas such as environmental citizenship (Finland [10], UK [16]), scientific habits of mind (Indonesia [11], Turkey [12]), future thinking (Malaysia [34]), science communication (USA [35]), genuine interest (Taiwan

[29, 36]), informal reasoning (Turkey [18, 33]), and scientific performance (Taiwan [37]). This expanded thematic scope indicates that SSI is no longer viewed solely as a mechanism to enhance reasoning skills but as a comprehensive pedagogical platform to cultivate cognitive, affective, ethical, and civic competencies.

Furthermore, the pattern of research dissemination exhibits a shift from conceptual papers toward empirical classroom-based interventions. Many studies now involve quasi-experimental designs [24], mixed-methods approaches [38], and performance-based assessments that examine student learning processes in authentic socio-scientific contexts [37]. Countries such as Indonesia, Taiwan, Malaysia, and Turkey have increasingly published empirical studies demonstrating the feasibility of SSI integration in secondary science classrooms.

The findings of this review show a noticeable progression compared with earlier meta-analyses. For instance, Genisa's review [21] identified that SSI research was still concentrated primarily in developed nations, particularly the United States and Western Europe. In contrast, the present analysis reveals a more diversified landscape, where countries such as Indonesia, Malaysia, Brazil, and Turkey contribute substantially to SSI publications.

Similarly, earlier reviews by Tekin and colleagues [39] highlighted that SSI research primarily revolved around argumentation and decision-making. While these remain central, the current review shows that more recent studies explore broader themes, including environmental stewardship [10, 16, 24, 40], socio-emotional engagement with controversial issues [29, 36, 41], and future-oriented scientific reasoning [18, 33-34]. These emerging directions signal a developmental shift in the field driven by global educational priorities such as sustainability, climate action, and citizenship education.

The increasing spread of SSI research across continents can be attributed to several key factors. First, educational systems worldwide are moving toward science curricula that emphasize critical thinking, scientific literacy, and community relevance. SSI offers a pedagogical structure that naturally aligns with these curriculum reforms. Second, global crises such as climate change, pandemics, and biodiversity loss have intensified public debates involving scientific evidence and ethical decision-making, making SSI-based teaching more urgent and contextually meaningful. Third, the use of culturally relevant SSI topics, including food safety in Indonesia, energy-related controversies in Spain and Turkey, and genetic engineering issues in Taiwan and Japan, illustrates how local socio-scientific problems can become powerful and meaningful contexts for student learning.

These developments suggest that SSI has matured into a transdisciplinary approach with substantial potential to reshape science education worldwide. The expanding diversity of nations and topics represented in the literature also confirms that SSI is adaptable to various cultural [10, 22], environmental [24], and socio-political settings [16]. Consequently, the global trajectory of SSI research indicates not only a rise in scholarly attention but also a shift toward more context-sensitive, student-centered, and future-oriented science pedagogy.

3.2 Types and domains of SSI across countries

The analysis of SSI topics used across the sixteen countries reveals that the selection of issues is strongly shaped by local sociocultural conditions, environmental concerns, technological developments, and national priorities in science education. Although SSI research is unified by its focus on integrating science with real-world problems, the reviewed studies show that the domains of SSI used in classrooms vary widely across regions. This diversity reflects the extent to which SSI provides a flexible framework that can be adapted to different societal contexts.

Environmental issues emerge as the most prevalent domain across countries. Studies from Indonesia , Spain, Malaysia, Finland, and the United Kingdom frequently employ issues such as climate change [14], plastic waste [30], river or soil pollution [20], acid rain [42], fossil-fuel dependence [41], coal mining [28], and ozone depletion [33]. These themes align closely with global sustainability concerns and resonate strongly with students' lived realities, particularly in regions facing ecological degradation or rapid industrial growth.

Energy-related controversies also constitute a major SSI category. Research from the United States, Germany, Taiwan, and Turkey commonly examines nuclear energy [43], solar energy [17], fossil fuels [16], energy transitions [19], and public perceptions of risk [31, 35]. These issues link scientific concepts with societal debates on decarbonization, renewable technologies, and national energy policies.

Another dominant category involves biotechnology and genetic engineering. Studies from Japan and Taiwan frequently explore genetically modified food [44], gene therapy [18], allergy-alleviating crops [15], and medically related genetic technologies [39]. Turkey also contributes extensively through studies on cloning [45], organ transplantation [43], radiation exposure [12], and broader biotechnology ethics. These issues highlight the ethical and scientific complexities of modern biological sciences.

Health-oriented SSI appear in several countries, including the United Kingdom, Australia, and Taiwan. Examples include public health measures, breastfeeding versus formula feeding [9], soil quality as a determinant of health [11, 35], and pandemic-related health communication [29, 42]. These topics reinforce the importance of teaching students to interpret evidence and evaluate competing claims within health-related controversies.

A notable feature in the dataset is the presence of culturally embedded SSI, particularly in Indonesia and Taiwan. Issues such as food safety practices involving borax or cyanide [3], local cosmetic safety [13], betel-leaf chewing [11], and region-specific energy or agricultural challenges [46] show that SSI can function as a bridge between scientific concepts and culturally meaningful practices. These forms of context-rich SSI enhance relevance and allow students to critically evaluate scientific evidence in relation to cultural norms.

Compared with earlier reviews, particularly Tekin's analysis [39] and Genisa's [21] systematic review, the present findings demonstrate a marked expansion in both the range and contextual specificity of SSI topics. While earlier studies emphasized argumentation and decision-making around classical controversies such as climate change, nuclear energy, and genetic engineering, the current synthesis indicates the emergence of broader and more diverse domains, including environmental citizenship, scientific habits of mind, and culturally grounded SSI.

Earlier literature also highlighted that most SSI topics were drawn from global controversies [47]. In contrast, the current review shows a more balanced distribution between global and local issues. Countries such as Indonesia, Taiwan, and Malaysia now incorporate distinctly local socio-scientific challenges into classroom instruction, demonstrating a shift toward contextually relevant SSI that were not widely reported in previous reviews.

Another key difference from earlier analyses is the increasing presence of health-related SSI in recent years, likely influenced by the COVID-19 pandemic and the rising importance of health communication. This trend was not prominent in studies published before 2018 but now constitutes a significant strand of SSI-based research.

The wide variation in SSI domains across countries underscores the adaptability of SSI as a pedagogical tool. Environmental issues dominate in regions where sustainability is a central national agenda or where ecological problems are visible in students' daily lives. Energy-related issues are more prevalent in countries undergoing transitions toward renewable energy or navigating public controversies regarding nuclear technologies. Biotechnology-oriented SSI thrive in regions with strong technological and medical infrastructures.

The presence of culturally embedded SSI in several Asian countries demonstrates that integrating local issues can enhance the meaningfulness of science learning, support cultural relevance, and promote critical reflection on traditional practices. Such findings affirm the potential of SSI to bridge scientific content with cultural and societal realities, helping students develop scientifically informed viewpoints that are sensitive to socio-cultural nuances.

The evidence indicates that the selection of SSI topics is strongly shaped by regional priorities and societal conditions. This suggests that SSI-based instruction has the capacity to support both universal scientific competencies and culturally responsive science education. It also highlights the need for future SSI research to explore how cultural context influences students' engagement, reasoning, and decision-making across different issue domains.

3.3 Instructional approaches and pedagogical orientations in SSI implementation

The reviewed studies show that SSI do not operate as a single instructional method but primarily serve as a context for learning. SSI provides real-world situations through which teachers implement inquiry activities [16], contextual learning [11], dialogic engagement [19], and other student-centered approaches [6, 29, 32]. Across the sixteen countries in this review, SSI is used to connect scientific concepts with authentic societal problems, demonstrating its flexibility in supporting scientific understanding, ethical reflection, and community-oriented engagement.

The most common approach is inquiry-oriented learning, where SSI prompts students to investigate phenomena, analyze evidence, and relate scientific findings to social concerns, particularly in Canada, the United Kingdom, and Taiwan. Context-based learning is also widely used, especially in Indonesia, Spain, Malaysia, and Taiwan, with SSI topics drawn from local environmental, health, or cultural issues. This strengthens the relevance of science by linking content to students' everyday experiences. Many studies employ dialogic and discussion-focused activities, using SSI to stimulate conversation, collaborative sense-making, and the examination of social implications. Countries such as Turkey, Spain, and the United States frequently adopt these approaches.

Other studies incorporate role-play [24], simulations [30], and scenario-based learning [14], enabling students to assume stakeholder perspectives and navigate socio-scientific controversies. Project-based learning appears in work that asks students to design solutions or develop community-oriented initiatives, with SSI providing authentic and meaningful contexts for such projects [9].

Compared with earlier reviews [21] that portrayed SSI pedagogy as centered on structured reasoning, the present findings show a broader shift toward inquiry, contextualization, and dialogic participation. Previous analyses also focused largely on Western contexts, whereas current research shows more diverse adaptations across regions. Inquiry-oriented approaches remain more common in Western countries, while context-rich and culturally grounded uses of SSI are particularly evident in Asian nations such as Indonesia, Malaysia, and Taiwan.

The evidence indicates that SSI operates most effectively as a contextual framework rather than a fixed instructional method. When positioned as the foundation for inquiry, discussion, projects, or simulations, SSI supports learning environments that mirror the complexity of real scientific and social issues. Inquiry-oriented activities help students understand how scientific knowledge is constructed, contextual learning strengthens cultural relevance, dialogic and role-play approaches encourage socio-emotional engagement, and project-based tasks foster student agency. These findings demonstrate that SSI enriches science education by anchoring learning in meaningful, authentic, and culturally relevant issues that connect with students' lived experiences.

3.4 Challenges, opportunities, and future directions

The reviewed studies show that while SSI-based learning offers substantial benefits for developing reasoning, engagement, and citizenship competencies, several challenges still hinder its full implementation. Teachers often struggle to facilitate open discussions and manage conflicting viewpoints, especially when issues involve ethical tensions [16, 18]. Limited instructional time and rigid curricula also restrict opportunities for in-depth SSI inquiry. Another recurring difficulty concerns assessment, as many countries lack validated tools to measure argumentation, socio-ethical reasoning, environmental citizenship, or future-oriented thinking. In some regions, particularly developing countries, limited resources and the absence of localized SSI materials further complicate implementation. Despite these constraints, the literature highlights significant opportunities, including increasing access to digital learning tools, rising societal awareness of climate change and public health, and the growing use of culturally grounded SSI contexts in countries such as Indonesia, Taiwan, Malaysia, and Turkey.

Compared with earlier reviews, which mainly emphasized challenges in argumentation and decision-making [21], the present analysis reveals that barriers now extend into areas such as metacognition, media literacy, and digital misinformation. Previous literature also tended to present SSI challenges as universal, while the current review identifies contextual differences. Teachers in western countries primarily report issues with ethical facilitation and assessment, whereas teachers in developing nations struggle more with resources and curricular limitations [8]. Additionally, earlier work highlighted argumentation and decision-making as key priorities for future research, whereas more recent studies increasingly focus on sustainability, environmental citizenship, and future thinking, reflecting alignment with global agendas such as the Sustainable Development Goals.

The findings indicate an urgent need for sustained professional development that prepares teachers to navigate controversial issues, guide ethical reasoning, and use appropriate assessment tools. Curriculum flexibility is also essential so that SSI inquiry can unfold in sufficient depth. The lack of reliable assessment instruments signals a priority area for future research, particularly in developing rubrics and performance tasks that capture the multidimensional nature of SSI learning. The opportunities identified in the literature suggest promising directions for expanding culturally responsive SSI frameworks, leveraging digital platforms to support inquiry and debate, and integrating sustainability-oriented SSI to foster informed and responsible citizenship. Overall, SSI scholarship is moving toward deeper contextualization, broader learning goals, and stronger connections to global educational priorities.

4 Conclusion

The findings of this systematic review reveal that SSI has become a significant and expanding focus in global science education from 2015 to 2024. Across sixteen countries, SSI is implemented through diverse environmental, health, energy, and biotechnology themes that reflect national priorities and cultural contexts. SSI primarily operates as a contextual framework rather than a fixed methodology, enabling its integration into inquiry-oriented learning, contextualized instruction, dialogic engagement, and project-based activities. These contexts collectively support a wide spectrum of student competencies, including argumentation, decision making, critical and higher-order thinking, scientific literacy, scientific habits of mind, environmental citizenship, engagement, and future thinking. The review also identifies persistent challenges, such as limited assessment tools, curricular constraints, and the need for teacher support, along with emerging opportunities related to digital SSI. As a whole, the review illustrates how SSI has shaped science education worldwide by linking scientific content to real-world societal problems and by preparing students with the cognitive, ethical, and civic capacities necessary for navigating complex global challenges.

We would like to thank the Lembaga Pengelola Dana Pendidikan (LPDP) Indonesia for funding the study and our publications as well as the supervisors who have guided and evaluated these publications.

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