

Science Education for Social and Ethical Responsibilities: A Systematic Literature Review

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ABSTRACT

For a sustainable future, scientists and educators are emphasising the social and ethical values associated with science. In this perspective, science education is seen as "promising" for fostering the values and skills necessary to become well-informed citizens in young minds. The researcher analysed the favourable aspects of the idea of teaching science with its social and ethical responsibility. A review of science education studies included focusing on social and ethical issues. A total of 26 papers, covering 2003 to 2023, were carefully examined to determine their applicability in the aforementioned context. This paper also attempts to discuss the evolution of research in science education, shifting from a more conceptual understanding to its social and ethical relevance in society. The paper underlines the issues and challenges that lead to identifying the need to discuss science education with real-world problems by situating it in its social, political, and cultural context. The paper argues that a framework needs to be developed which is both contextually and culturally relevant for learners. Additionally, numerous aspects of science education for global social and ethical responsibility were addressed.

KEYWORDS: Science Education; Social and Ethical Responsibility; Social Justice; Socially Responsible Science Education (SRSE); Socio-Scientific Issues (SSIs)

1 Introduction

We are currently dealing with significant global crises affecting humanity, where equity and inclusion of everyone to deal with these issues have become one of the major aims for the

entire education system. For a sustainable future, scientists and educators are promoting social and ethical values in science. In this perspective, science education is seen as "promising" for fostering the values and skills necessary to become well-informed citizens in young minds. As the existing science curriculum conforms with the criteria of 'pure' theoretical knowledge laid down by the elite, it leads to demanding a more democratic environment within the classroom (Rampal, 1992). Hodson (2003), in the study "Time for Action", makes powerful arguments in support of such a science curriculum to combat major social and environmental issues. Bencze et al. (2020) emphasised the importance of "science-in-context" approaches in science education, which involve integrating science with social, cultural, and ethical issues. The lack of awareness and education about social, cultural, and ethical issues perpetuates the marginalisation of underrepresented students in science education (Yerrick & Gilbert, 2011). Thus, it is significant in communicating issues of social and ethical responsibility in science education, particularly because of its connection with better decision-making, democratic participation and social integrity (Frazer & Kornhauser, 1986).

The Dominant discourse in science education and research were mostly inclined to a positivist approach of scientific inquiry and science literacy which is further followed by persistent narratives related to STEM education where science education fulfils the need of the global marketplace of the future world. Nevertheless, the recent trend in development literature has moved towards tackling issues of society through enabling scientific citizenship and a socially responsible science education. If we are not training students to critically link scientific knowledge and skills with realities of life, communities will continue to grapple with superstitions, pseudo-scientific logic and socio-scientific challenges such as climate change, pollution, genetics, etc. This transformation means disengaging from traditional approaches to teaching science and engaging with a critical, socially relevant pedagogy in science. In this context, Barrett & Nieswandt(2008) raise concern that science teachers rarely discuss socio-scientific issues in senior physical science courses in high schools(Cross & Price, 2002), possibly

because they assume that students will take what they learn in science and apply it to the content of social studies courses, where controversial issues are expected to be discussed.

Considering the above need, researchers in science education have also shown a major turn. Due to the need for improvement, techniques adapted from the sciences are currently being developed to enhance teaching science. Research in science education shows a major shift in research trends where studies focusing on more cognitive and conceptual understanding of complex scientific phenomena to different learning models have shifted to its social, cultural, political and ethical implications (Koireng, 2020). In the past two decades, these trends have witnessed a spectrum of variation at different levels. The central ideas of studies exploring argumentation as relevant for solving actual life scenarios of science learners (Lee et al., 2009; Abell & Lederman, 2007) shift away from topics such as argumentation, inquiry-based learning, and scientific modelling (T. C. Lin et al., 2014) then an increased concentration on inequality within science education and STEM issues (T. J. Lin et al., 2019). Thus, epistemology, history, philosophy, and ethical and cultural concerns have been the main topics of research on teaching science, curricula, content selection, and teaching-learning materials. However, the majority of contributions were from English-speaking countries, with the USA, UK, and Australia (Lee et al., 2009; T. C. Lin et al., 2014; T. J. Lin et al., 2019).

Science for social and ethical responsibility emerged as a vital approach to teaching science that focuses on promoting equity, inclusivity, and sustainability. Ensuring equity and access to science education for all students and promoting environmental stewardship and sustainability are important aspects of socially responsible science education. The concept of the nature of science education discussed in (Allchin et al., 2014; Höttecke & Allchin, 2020) emphasized the importance of teaching students about the social and cultural dimensions of science, including the historical and contemporary contexts in which scientific knowledge is produced and used. As this kind of approach encourages students to critically examine scientific claims and consider the ethical implications of scientific research. The use of problem-based and case-based learning, as outlined in

Allchin (2013) and Bencze (2017), provides a pedagogical framework for engaging students in real-world issues that require interdisciplinary and ethical considerations. Similarly, Hadzigeorgiou (2012) argued for the integration of liberal and humanistic traditions in science education, which involves recognising the personal relevance and social responsibility of scientific knowledge. These ideas contribute to the development of socially responsible science education (SRSE) by promoting critical examination of scientific claims and encouraging collaboration, communication, and interdisciplinary thinking.

2 Conceptual background

This paper discusses the role of social and ethical values in science education. The paper draws arguments guided by two frameworks mentioned above, that is, the Responsible Research and Innovation (RRI) framework and critical pedagogy. The RRI Map (Bardone et al., 2023), a structure for responsible scientific instruction, is presented in this paper. It notes three primary activities: appreciating the scientific enterprise, overcoming obstacles, and investigating theoretical opportunities. The map links RRI with current theories of science education, including Nature of Science, Inquiry-Based Learning, Socio-Scientific Issues, and Citizenship Education. It underlines the need to separate responsibility and stress the process above the results. The RRI Map advances RRI for use in education. On the one hand, Critical pedagogy is fundamentally a theory developed by Brazilian educator Paulo Freire in relation to his book "Pedagogy of the Oppressed" in 1970. Freire advocates for dialogue, students to pose questions, and the use of a critical consciousness, firmly connecting education to social injustices. Important figures involved in the construction and definition of "critical pedagogy," including theorists Henry Giroux, Peter McLaren, and Michael Apple, help ascertain the parameters of this site in critical pedagogy focus; Giroux discusses the role of educator's in instilling critical thought and civic responsibility, McLaren discusses the importance of teacher's relationships with students, and Apple relates education to power and social justice. Together, these theorists theorise the understanding of critical pedagogy as an empowerment of learners to think critically

about their communities and social realities in which they live and seek to change(Lamsal, 2024).

This research provides a perspective and conceptual understanding of social and ethical aspects of science education for social justice. It contributes arguments, issues and challenges of integrating social and ethical concerns in science education curriculum at different levels. By addressing these challenges, science education can become more relevant for the learner as well as lead to scientific citizenship. The study presents distinct examples of adopting a spectrum of approaches to emphasise social and ethical issues in science teaching. This study further incorporates the research methodology detailing the inclusion and inclusion criteria, sources of research, selection criteria, methodology, conceptual ideas of research, contributions from different countries, and results of recent research. In conclusion, the study manages to present educational implications, limitations and suggestions for future research.

3 Methodology

The debate on placing science into its social, political and cultural context has a huge discourse on its appropriate implementation. Scientists, teacher educators and school teachers have realised the urgent need to teach science by integrating its social and ethical implications. This research paper manages to review the research papers arguing on the science education for social and ethical responsibility and delves deep into the arguments made by science educators and researchers on how to teach science in a more socially and ethically responsible way.

PRISMA Method: PRISMA is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses. PRISMA method can be used as a basis for reporting systematic reviews with objectives other than evaluating interventions (<http://www.prisma-statement.org>).

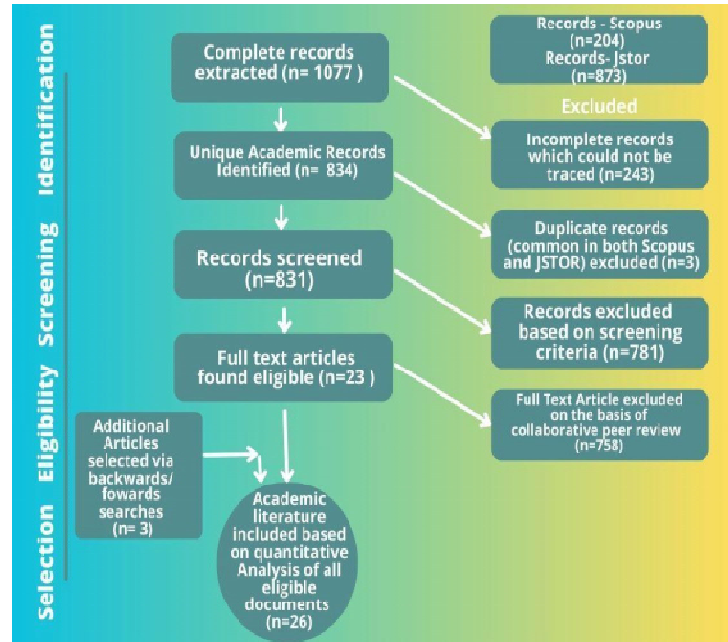


Fig. 1 PRISMA method flow chart

Data collection: As shown in Figure 1, studies to be reviewed in this review study, were identified by searching the following databases: Jstor and Scopus. All databases were searched using the keywords: socially responsible science (OR science education); ethical responsible science (OR science education). In other words, social/socially responsible/ responsibility in science/ science education. Similarly, ethical/ethically responsible/ responsibility in science/ science education. The number of studies in each database has been reported.

Inclusion criteria for records considered in the study were based on their relevance to the research topic. Exclusion criteria included records that did not meet the specific research requirements.

Information Sources: Records were collected from Scopus and JSTOR databases.

Search Strategy: A systematic search was conducted using relevant keywords and advanced search to retrieve records from Scopus and JSTOR databases.

Selection Process:

- A total of (n=1,077) records were initially identified from Scopus (n=204) and JSTOR (n=873) databases.
- Duplicate records (three common in both Scopus and JSTOR) were excluded, leaving 834 unique academic records.
- Records were screened based on eligibility criteria, resulting in 831 records for further consideration.
- Full-text articles were found eligible (n=26) for detailed analysis.

All the research papers (n=26) were coded manually and analysed thematically in detail. A risk of bias assessment was conducted to evaluate the quality and potential bias of the included studies. The effect measures used in the analysis were based on the research objectives and outcomes of the included studies. The synthesis methods employed for the analysis were based on the nature of the data and research objectives.

4 Result & Discussion

Study selection:

The study of literature review was selected through several steps. First, all the repeated or duplicate papers were discarded. Then, a thorough reading of the research paper was done by the researcher, those articles that were found non-relevant to the theme were excluded. A total of 1077 research papers were found in the theme, where 873 research papers from JSTOR and 204 from Scopus were found as the theme is relatively new in the area of science education. Most of the papers were related to the different areas of science education. 1024 research papers were found to be less relevant to the basic idea of the review. For instance, most of the research papers were focusing on the management and corporate social and ethical responsibility, sustainable development and green environment in the industrial development sector.

At last, 26 research papers (15 from JSTOR & 8 from Scopus and three additional articles were selected through backward and

forward searches) were found most relevant to the central theme of the review study. Table 1 shows papers selected in both search engines with relevant key terms found in these papers.

Table: 1 Source of study selection

Search engine	No. of studies	Key terms found relevant
Scopus	8	social/socially responsible/ responsibility in science/ science education ethical/ethically responsible/ responsibility in science/ science education
Jstor	18	Democratic approach, critical pedagogy, socio-scientific issues, case-based study in science, science for social justice and equality

Data extraction

a) Inclusion criteria: During the selection process, five criteria were identified by the researcher to exclude/include research articles for the systematic research review. Research articles must belong to the education (science education) discipline. All papers should be 'research articles' published in journals. The papers belong to the past two decades (2003-2023) of research being done in a similar area. Abstract or title must involve the keywords mentioned above and the paper should be written in the English language only.

The selected research articles belong to social and ethical responsibility in science and science education discussed at different levels of the study, including 1) school education, 2) higher education (undergraduate/postgraduate/teacher education), 3) scientific associations, 4) Researcher, and 5) Policymaker/ curriculum developer.

b) Exclusion criteria: Incomplete and non-English language publications, Conference reviews, books, chapters, book reviews, conference papers, and surveys were excluded. Articles in the press, and beyond the education discipline were also excluded.

Nature of the studies

Table 2 shares the major categories of the nature of the study. Most of them were empirical and conceptual papers, including descriptive studies.

Table 2: Nature of the studies

S. No.	Nature of the study	Frequency	Target level of the study
1.	Experimental study	9	-School education level (mostly secondary level)
2.	Descriptive study	6	-Higher education (mostly engineering discipline)
3.	Conceptual paper	8	- Teacher education (both pre-service and in-service) -Scientific associations, Media and Society -Policymakers

Conceptual ideas of researches

Table 3 presents a gist of central ideas of all the papers involved in this systematic review. A major argument raises on socially responsible science and its challenges. The key ideas discussed here range from the emergence of arguments on various social and ethical concerns in science and technology to the major responsibility of scientists and scientific associations. Then, it also argues for the appropriate dissemination of scientific knowledge among laypeople through scientists, science communicators, teacher educators and school teachers.

Table 3: Conceptual ideas of selected researches

Conceptual ideas	Authors
Socially responsible science	Bektas & Tayauova, 2019; Bird, 2014; de Melo-Martín & Intemann, 2023; Fuchs & Tan, 2022; Heng, 2008; Jensen, 2022b; Kourany, 2013; Resnik & Elliott, 2016)
Social and Ethical Responsibility in science for social justice, Communication theory, Feminist philosophy of science	Scheufele, 2013; Bektaş & Gulzhanat, 2019; chamany, 2006; Garibay, 2015; Garibay, 2018; Strathern, Marilyn 2003; Weasel & Finkel, 2016; Conlon, E., 2008; Lathem et al., 2011; Ben-Zvi-Assaraf, & Ayal, 2010
Critical science education, Critical pedagogy, Culturally responsive pedagogy	Iyengar, R., & Bajaj, M. (2011); Feld Adriana, 2019; Delicado et al., 2014; Antunes et al. (2021); Gough, 2011; Boeren, Ellen, 2019; Lim & Li, 2022; Caruana, 2016

Emergence of socially responsible science

As Table 3 discussed that a significant number of studies (n=7) talked about socially responsible science as the central idea of their research. These studies mentioned that the approach encourages students to collaborate, communicate, and think critically about how science can impact society and the environment. Bird (2014) discussed the role of science in society should be focused on enabling democracy and informed decision-making. Discussion of the ethical implications of the use of scientific research was about procedures for democratic decisions and the allocation of authority and voice among competing societal groups. It is prominent that scientists have a right and responsibility to contribute to society and bring specialised knowledge that may be essential to addressing social concerns.

The concept of socially responsible science education and the importance of ethical considerations in scientific research and practice were discussed by Kourany (2013) and Resnik & Elliott (2016). They mentioned that this concept encourages students to consider the potential impacts of scientific research on society and the environment and to engage in responsible and ethical decision-making. Therefore, the need for science educators to promote open, reflexive, and socially responsible communication practices in scientific research and public engagement was realised (Jensen, 2022). Jensen discussed the ways in which scientific information is communicated and disseminated, and also raised concern to engage in critical reflection and analysis of scientific communication practices. These collective approaches emphasised the significance of interdisciplinary, ethical, and critical perspectives in science education that encourage students to engage in informed decision-making and responsible scientific practice.

Presely *et al.*, (2013) revisited the studies on socio-scientific issue-based classrooms and developed a framework for SSI-based education in science classrooms. The authors provided three important elements of SSI instruction-based education, which include design elements, teacher attributes and learners' experience. In addition, they also covered other peripheral elements that influence SSI-based classrooms, for instance, the classroom environment and the influence of social and political power. The authors successfully developed a framework for controversial issues in a science classroom with lots of flexibility and were also able to categorise do's and don'ts while using SSI-based instructions. In this row, Fuchs & Tan (2022) analysed four frameworks which can support socially responsible science education and reviewed the opportunities and challenges teachers feel are associated with their implementation. Teachers agreed that frameworks benefit student learning by providing a context for students to use and learn science. Teachers identified system-level factors that influenced framework implementation, emphasising the importance of an aligned curriculum.

While socially responsible science (SRS) is desired, the authors (de Melo-Martín & Intemann, 2023) contend that it is challenging to define exactly what it involves. They contend that

by offering precise and detailed descriptions of particular duties, philosophers of science can promote SRS more successfully. They contend that considering these factors is beneficial in three ways: it offers direction for those creating insightful accounts of SRS, it emphasises how difficult it is to do so, and it demonstrates that general calls for SRS are unlikely to result in significant changes to scientific research agendas or practices. Additionally, they stressed the significance of establishing greater conceptual clarity on SRS due to the term's ambiguity and debates over its definition. Theoretical clarification, in their view, can assist in clarifying what normative recommendations follow from promoting SRS. The above ideas contribute to the development of socially responsible science education (SRSE) by promoting critical examination of scientific claims and encouraging collaboration, communication, and interdisciplinary thinking.

Social and Ethical Responsibility in science for social justice

The above discussion results in the higher social and ethical responsibility of the scientists and science communicators in promotion of social and ethical responsibility in science. In this context, Scheufele(2013) discusses how to appropriately communicate science in social settings as it influences market and policy debates. The study discussed various problems in science communication, for instance, the politics of legitimation of knowledge (journal ranking nowadays decides the authenticity of the scientific inference), the lesser responsibility of scientists owned by them, and the conversion of the traditional infrastructure of conveying the information (considered appropriate). A decline in the 'new holes'/space as termed by Scheufele (2013), given to science and technology in the news in traditional media. The lack of trained journalists in science communication considered as a big issue in communicating science. Another concern was that polarisation of media towards a particular ideology may interfere with the scientific and technological process. These media portrayals influence the decisions of policymakers. The authors raised concern over 'framing' which can hugely impact the public understanding of science; a well-framed scientific concept can help to make better

decision-making among non-science audiences. Economic, social, and political developments encumber responsibilities to society, including scientists. However, Bektas & Tayauova (2019) argued that social scientists have higher responsibilities due to the certainty of natural science rules and the difficulty in providing direct solutions to social issues. The model revealed that the social responsibility of social scientists follows a hierarchical path. Universities, in this framework, provide environments for people to perceive and argue events, increasing awareness through rationalisation.

These studies also raise concern for teachers and teacher educators to communicate science responsively in their classrooms as well. In this context, Chamany(2006) focused on the biology curriculum at the school level. The study incorporated social and ethical issues and used as a case in biology classrooms. For instance, the Tuskegee syphilis trial (HIV), stereotypes stemming from the social Darwinism movement, and Patricia Schneider's "The Genetics and Evolution of Human Skin Colour" were used for teaching epistasis and natural selection. Another was DNA identification (relating it to the incident of 50 children displaced during the war and then recruited by their parents by DNA identification (science for social justice). Findings reveal that giving social and political appetisers to improve the engagement of the students was successful. It helped in building connections between concepts and socially relevant issues. The long-term effect will be for non-science learners to become more socially responsible learners in society. Similarly, Strathern(2003)rethought and focused on two empirical casesbioethics in reproductive technologies and compensation claims for environmental pollution. The study made the case for a socially robust science. The author talked about the necessity for a descriptive "society" that consider context in asymmetric situations, like a large-scale mine in Papua New Guinea that resulted in environmental destruction and locals' distrust of science. The case emphasised the significance of taking context into account in societies that produce research since it can be obtained elsewhere. In this row, Weasel & Finkel (2016) added deliberative democracy (DD) activities to undergraduate biology classes increased the

proportion of students who provided accurate responses at the end of their engagement with sources by 22%. The deliberative model stressed subjects like genomic sequencing and genetically engineered organisms that are not included in classroom understanding. Students acquired self-assurance in their knowledge and in their ability to interact with contemporary biological environments. Hormones, E. coli, and climate change were examples of biology topics that were not covered in the classroom. The study encouraged students to incorporate social themes into their coursework either implicitly or overtly.

An interesting finding to explore how the science courses were developing social and ethical responsibility, Garibay (2015) examined differences between STEM and non-STEM students at the end of college on the values they place on contributing to the creation of a more equitable society. The value of working for social change is often viewed by STEM students as being less relevant to their career aspirations; there are variances between underrepresented students of colour and their non-underrepresented peers. Another study by Garibay (2018) revealed that when STEM bachelor students have high social agency, they believe in relevant research to be done in favour of society. Students with low social agency believed that it is not relevant to work on research to be done in favour of society. Overall, the majority of STEM students had medium/low social agency, and they believed in less relevant research (i.e. less socio-political involvement). Therefore, a wider emphasis on socially responsible engineering is required in light of the crisis in engineering education. Delivering equitable and sustainable engineering solutions cannot be done with a restricted emphasis on employability skills. Students must learn how to place their work in a larger societal perspective. Bucciarelli (2009) as cited by Conlon (2008), advocated completely overhauling the engineering curriculum to include the social component in a multidisciplinary framework. However, this change was extensive and unlikely to be implemented shortly, at least from the Irish standpoint. Furthermore, Lathem et al. (2011) analysed students' perceptions of how the programs affected their awareness of sustainability concerns, engineering roles and responsibilities. The self-perceptions of female students on their

increasing technical knowledge and societal duties as engineers differed favourably. Similarly, Ben-Zvi-Assaraf & Ayal (2010) also reported a similar result in their study of a university course that integrates their technical expertise with sustainability-focused objectives. 30 chemical engineering fourth-year students were the subject of this study. Engineering education now emphasises sustainability as a central concern, covering topics like corporate sustainability and environmental concerns. The results imply that to compete in the global economy, engineering students can acquire industrial-environmental consciousness.

Interventions for socially and ethically responsible science education and the challenges

The above research studies indicate the requirement for socially and ethically responsible science education, while highlighting the issues of educational accessibility and the challenges of implementing them in various educational settings. Contextualisation of science education through culturally relevant pedagogy and community involvement can help address these issues. Iyengar & Bajaj (2011) examined the lack of contextualisation and social science components in environmental education in Bhopal, India, highlighting the neglect of these components in traditional, natural science approaches. It also underlined the lack of coverage of environmental citizenship and social issues. The article discussed the disconnect between national educational policy frameworks and the actual inclusion of environmental education in local and national textbooks. It calls for policymakers and activists to recast education for sustainable development in India as part of a comprehensive strategy, promoting environmental education as a continuous activity outside the classroom. Feld Adriana (2019) took a similar approach and looked at how the Cold War affected discussions on fundamental research and Science and Technology Policies (STPs) in the research community of Argentina. The semi-peripheral scientific context, the "democracy-totalitarianism" contradiction, and the "development-dependence" dichotomy were identified as the three discursive configurations that surround science and technology. The connection between these discourses and the institutional

structures put forth by significant members of the research community to implement STPs was also explored in this paper. The study emphasised the significance of the research community's involvement in defining what basic research is, the importance of local/regional issues, and the significance of basic research in a country that is on the periphery of the world. In this context, Delicado et al. (2014) examined the function of scientific associations in both science and society. It investigated scientific associations in Portugal using a multi-method, quantitative, and qualitative approach. Peer communication, research promotion, science dissemination, the representation of professional interests, and policy advice were the five key tasks that have been recognised. The study concluded that, as a result of the internationalisation of science, transnational communication, collaboration, and competition between scholars have taken on greater significance than intra-national dynamics. The connections between science and other social sectors continue to have a strong national context and are reliant on particular arrangements and behaviours of governmental, commercial, and other social actors. The article's purpose was to open a dialogue about the functions of scientific associations and their relationship. A similar intervention was done by Antunes et al. (2021), which studied Antimicrobial resistance (AMR), which is a worldwide social issue that calls for the participation of experts and residents. Young people in Portugal are becoming less motivated to pursue professions in science, and there is a general lack of awareness regarding the proper use of antibiotics and AMR. In 2018, the University of Porto introduced *MicroMundo@UPorto*, an experimental pedagogical approach for service learning, in response to these problems. The project aimed to raise younger students' interest in science and AMR consciousness while also enhancing the academic performance of university students and equipping them with a variety of personal, social, and scientific abilities. Out of 80 samples, 20 yielded 50 isolates, mostly from Gram-positive genera, and presumed positive results. 90% of the students gave their involvement a positive evaluation, and strongly recommended the project to other schools. Thus, the *Micro Mundo* project model presented an example that can be effectively expanded

across Portugal and utilised in microbiology education, resulting in individuals who are both scientifically competent and socially responsible. Likewise, specifically, over the last ten years, Gough (2011) examined Australian Government initiatives in the field of environmental education. The implementation strategy for the Decade of Education for Sustainable Development (DEWHA, 2006), activities from two national action plans (Environment Australia, 2000, and DEWHA, 2009), and changes to the Australian Curriculum were all examined. The metaphor of the Curriculum as a jigsaw piece, the continual struggle for survival in the formal Curriculum, and the ongoing conflicts between science education and environmental education in Australia's official school curriculum served as the inspiration for this study. The study argued that preserving an open ending is crucial and that environmental education cannot and should not be constrained by a traditional curriculum jigsaw frame.

As the environment is closely connected with SGDs, the UN's "2030 Agenda for Sustainable Development" includes SDG 4, which was established in 2015 as a strategy for prosperity for people, the planet, and all life. Boeren(2019) examined the ten targets within SDG 4 from micro, meso, and macro perspectives; the essay used structure and agency theory. In fulfilling the SDG 4 targets, it emphasised the shared accountability of people, educational and training institutions, and regulatory governments. The involvement of parents, kids, teenagers, and adult learners at the micro level of education was also included in the essay because these groups were the most pertinent. Likewise, Caruana et al. (2007) claimed that to solve local environmental challenges, local communities and schools work together to provide critical environmental education. Through the critical production of knowledge and cooperative problem-solving, this strategy fosters synergistic linkages between knowledge systems and empowers the grassroots to effect change. Since 2000, the fairtrade movement has expanded dramatically, with fair trade goods sales alone increasing by 20% in Europe. Schools frequently collaborate with communities as part of environmental education programs to foster critical knowledge of the responsibilities that communities play in addressing environmental challenges. In response to this, Lim &

Li (2022) described a learning strategy that gives participants with a safe method to explore how a virtual infection spreads through society. In March 2021, the intervention was implemented with nine undergraduate teachers-in-training at a Singaporean teacher-education institute. Participants were asked to consider the relationships between their individual choices and how they affected the larger community. The relationship between the virtual activity and real-life circumstances was made easier with the use of the Socially Responsible Behavior via Embodied Thinking (SORBET) approach. According to the study, the cultural-historical activity theory (CHAT) framework can be used as a useful lens for examining how the many components of the SORBET approach interact with one another and how this helps the approach achieve its goal. The research indicated that a Hashiwokakero activity, where learners negotiate and collaborate alongside each other, could be an authentic context of action while a virus is being diffused among community members.

Results of recent researches

Table 4 incorporated 11 research studies among the selected 26 studies to analyse separately the latest conceptual and pedagogical contributions in socially responsible science education. The following studies found it imperative to discuss separately as they respond to contemporary SSIs challenges, propose frameworks and innovative interventions beyond the traditional classroom teaching learning process.

Table 4 Results of recent researches

S.no.	Title of the study	Author's name	year	key ideas discussed
1.	Beyond Traditional Measures of STEM Success: Long-Term Predictors of Social Agency and Conducting Research for Social Change	Juan C. Garibay	2018	STEM graduates are crucial for addressing poverty and inequality.

2.	Communicating science in social settings	Dietram A. Scheufele	2013	Challenges in communicating science to the public and the need for effective science communication efforts at the societal level.
3.	Socially Responsible Science Is More than "Good Science"	Stephanie J. Bird	2014	The scientists have ethical and societal responsibilities that go beyond conducting research.
4.	Frameworks Supporting Socially Responsible Science Education: Opportunities, Challenges, and Implementation	Travis T Fuchs and Yuen Sze Michelle Tan	2022	Four framework that can support socially responsible science education: 1) Science-Technology-Society-Environment (STSE) education, 2) Socio-Scientific Issues-based education, 3) Critical Pedagogy of Place, and 4) Science & Technology Education Promoting Wellbeing for Individuals, Societies & Environments (STEPWISE).
5.	Developing open, reflexive and socially responsible science communication research and practice	Eric A. Jensen	2022	The availability of useful tools and frameworks for developing socially responsible science communication practice.

6.	Personal Spaces and Communal Consequences: Navigating Geographical Tensions with the Socially Responsible Behavior through Embodied Thinking (SORBET) Project	Lim, Kenneth Y.T., Li, Samuel C.X.	2022	The study describes a learning strategy that gives participants a safe method to explore how a virtual infection spreads through a society. The cultural-historical activity theory (CHAT) framework can be used as a useful lens for examining how the many components of the SORBET approach.
7.	Socially responsible science: Exploring the complexities	de Melo-Martín, Inmaculada, Intemann, Kristen	2023	Socially responsible science (SRS) is desired. It demonstrates that general calls for SRS are unlikely to result in significant changes to scientific research agendas or practices.
8.	Science, Politics/Policy and the Cold War in Argentina: From Concepts to Institutional Models in the 1950s and '60s	Feld Adriana	2019	The paper makes the case that the Cold War had an impact on the definition of research that was best suited to regional circumstances, resulting in variations in research and Science and Technology Policies (STPs) .

9.	The Ethical Challenges of Socially Responsible Science	Resnik, David B., Elliott, Kevin C.	2016	Scientists can address ethical challenges associated with socially responsible science by working with scholars, expressing value assumptions and commitments, and differentiating between data and findings.
10.	Science Ethics and Social Responsibilities of Scientists	Bektaş, Çetin, Tayauova, Gulzhanat	2019	Scientists should show effort and responsibility to contribute to solutions for humanity and society by providing opportunities to their own society and humanity.
11.	MicroMundo@UPorto: An experimental microbiology project fostering student's antimicrobial resistance awareness and personal and social development	Antunes, P., Novais, C., Novais, Â., Grosso, F., Ribeiro, T. G., Mourão, J., Perovic, S. U., Rebelo, A., Ksiezarek, M., Freitas, A. R., & Peixe, L.	2021	The MicroMundo project model found to be extended across Portugal and for education in Microbiology, fostering socially responsible and scientifically-literate citizens.

For instance, Garibay (2018) raised a significant consideration regarding the relevance of STEM graduates in solving societal problems (e.g., poverty and inequality) and the need for effective science communication to close the gap between scientific knowledge production and public understanding. Ethical responsibilities, such as social justice, fairness, honesty, and inclusivity, and societal benefits from applying scientific

discoveries to improve life and address common human concerns, are key dimensions defining the SSI profile of scientists or scientifically literate citizens, beyond mere research skills. Therefore, four educational frameworks (STSE Science-Technology-Society-Environment; SSI-based education Socio-Scientific Issues; Critical Pedagogy of Place; STEPWISE Science & Technology Education Promoting Wellbeing for Individuals, Societies & Environments) were proposed by Fuchs & Tan (2022), support responsible science education. In addition to this, the cultural-historical activity theory framework was proposed as a way to take the context in which socially responsible science may be incorporated more effectively into a piece like SORBET, an approach to learning simulating the spread of societal infection (Lim & Li, 2022). That call for socially responsible science itself does not move to effect real changes in scientific practice or in a research agenda. A little history in the form of the Cold War goes a long way in shaping the approaches adopted on how science adapted to regional contexts and influenced the STPs (Feld Adriana, 2019). That means socially responsible science aims to contribute toward solutions for the global challenges and engage society. Similarly, the Micro Mundo project, across Portuguese borders, as another example, represented in fact how education in microbiology can be used to foster not only scientific literacy but also social responsibility (Antunes et al., 2021). Viewed on a much broader level, the research presented here argued for a science-society integration and proposed that teachers should become more deeply committed through educational tools and collaboration to ethical, societal, and communicative responsibilities. Thus, these studies indicated an important shift in the discourse in science education research towards higher social responsibility, sustainability and the integration of ethical values. These studies move beyond mere content delivery to foreground individuals' roles as socially active actors within the complex scientific and societal networks.

This paper was built on arguments from the two frameworks, RRI and critical pedagogy. The findings pointed out that from the perspective of the RRI framework, science education must go beyond imparting technical skills. The reviewed studies revealed

a need for significantly more emphasis on RRI principles, anticipation, reflexivity, inclusion, and responsiveness in science education, despite growing recognition of social responsibility's importance. For example, several studies discussed how science education plays a critical role in some global challenges, such as climate change and health inequities. Only a few studies deal directly with the connection between these programs and the larger objectives of RRI, which are public engagement, equity, and sustainable development. Similarly, guided by the principles of Critical Pedagogy, findings reveal that science education must go further than training students in technical skills: it should adopt a broader perspective that incorporates social and ethical dimensions. These studies demonstrated that despite increased awareness of social responsibility in science education, more attention is needed to cultivate students' critical thinking, ethical reasoning, and social engagement. These gaps highlighted an invaluable opportunity for future research to explore how science education can better align with the principles of RRI and critical pedagogy, thus better equipping students to be responsible innovators and engaged citizens.

Limitations and Suggestions for Future Research

As the study adopted the PRISMA method for the selection of the research paper, the search was confined to JSTOR and Scopus databases, potentially overlooking relevant studies from other sources. Therefore, future research could broaden the search scope to include other relevant databases. In addition, the search strategy employed relevant keywords; the inclusion criteria may have unwittingly excluded some pertinent research studies. Future studies could refine the search strategy to incorporate additional synonyms or related terms to capture a broader spectrum of relevant literature. Furthermore, the analysis included a relatively small sample size of 26 research papers, which may limit the generalizability of findings. Future research studies could aim to include a larger and more diverse sample to strengthen the robustness of conclusions drawn from the analysis.

Future research could explore the longitudinal effects of socially responsible science education interventions on students' attitudes, behaviours, and societal contributions. Additionally,

comparative studies could investigate the effectiveness of different pedagogical approaches in promoting social and ethical responsibility in science education. Moreover, qualitative inquiries could delve deeper into the perspectives of educators, students, and stakeholders regarding the challenges and facilitators of implementing socially responsible science education initiatives. Finally, interdisciplinary collaborations could be fostered to address complex socio-scientific issues and develop innovative solutions that integrate scientific expertise with ethical considerations and societal needs.

Conclusion

For democratic science classrooms, SRSE can be used as an approach to discuss these prevalent issues to make our classrooms more critical and provide insights into society in the realm of Science and Technology in classrooms. It involves a critical analysis of Curriculum, pedagogy, content, and activities through the lens of the disadvantaged in science education. Discussing these issues in a science classroom can help students understand the ethical and social implications of scientific knowledge and its applications. It can help to promote critical thinking and problem-solving skills, empathy and compassion, and inclusivity and diversity. Additionally, discussing these issues can help to create an inclusive and diverse science classroom that values diversity and promotes equal opportunities for all students. This requires the necessity to analyse teacher education programs which ensure that teachers are prepared to teach science in a way that is socially responsible and meets the needs of their students. As mentioned, socially responsible science education aims to address issues of equity and inclusion in science education. Analysing teacher education programs can help identify areas where equity and inclusion are not being addressed and develop strategies to address these issues.

Notes

- Socially Responsible Science (SRS) promotes collaboration, critical thinking and ethical decision making in scientific research as well as in teaching and learning of science to address societal and environmental concerns.

- Frameworks such as Socio-Scientific Issues (SSI) issues are those issues which are social issues informed by scientific concepts and are controversial. SSI-based education promotes students' understanding of ethical considerations and responsible scientific practice.
- Communication of science in social settings faces obstacles such as media polarisation and a lack of trained science communicators.
- Teachers play a crucial role in integrating social and ethical issues into science education through case studies and community involvement, fostering socially responsible learners.
- Addressing challenges in science education requires contextualisation, community involvement, and alignment with sustainable development goals, while also considering local and regional contexts.
- Educational initiatives like MicroMundo@UPorto and learning strategies such as SORBET aim to empower learners with scientific competence and social responsibility, promoting critical thinking and problem-solving in real-world contexts.

Conflict of Interest

The authors declare no conflict of interest.

Ethics statement

This research upholds ethical standards by ensuring transparency in data handling.

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