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Research Article

Engaging Science Teachers in Socioscientific Issue-Based Pedagogy in Indian Classrooms

Meenakshi Kaushik[1], Sugra Chunawala[2], Deepa Chari[2]

[1]National Council of Educational Research and Training, Delhi, India
[2]Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, Mumbai, India

Abstract
The integration of Socioscientific Issues (SSIs) in science education has been widely recognised for its potential to enhance students' scientific literacy and engagement with real-world issues. SSIs provide a framework for students to explore issues that intersect with science and technology (S&T), allowing them to develop critical thinking, problem-solving, and decision-making skills. However, despite growing policy support, teachers often face challenges in implementing SSI-based pedagogy due to its multidisciplinary nature, lack of training resources, and time constraints. This study explores a prototype short-term intervention program aimed at equipping secondary science teachers with the knowledge and skills necessary for effective SSI-based instruction. Grounded in the theoretical frameworks of co-construction and Pedagogical Content Knowledge (PCK), the intervention engaged two experienced science teachers in a structured process of developing and implementing SSI-based learning modules. Using a qualitative case study approach, data were collected through semi-structured interviews, recorded intervention sessions, teacher reflections, and module analyses. Findings indicate that while teachers recognised the value of SSIs in fostering student engagement and critical thinking, they encountered difficulties in balancing scientific content with social dimensions, managing value-laden discussions, and aligning SSI instruction with curricular demands. The study identifies key strategies and resources that facilitated teachers' adaptation to SSI-based pedagogy, emphasising the role of reflective practices, contextualisation, and structured support in overcoming pedagogical challenges. By analysing teachers' evolving PCK, this research contributes to the development of targeted professional development programs that bridge the gap between policy aspirations and classroom practices, ultimately promoting the integration of SSIs in science education.

Keywords: Pedagogical Content Knowledge, Science Education, Socioscientific Issues, Teacher Professional Development

Correspondence
Meenakshi Kaushik
kaushik.meenakshi2287@gmail.com

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1. INTRODUCTION

The Socioscientific Issue[1] (SSI)-based approach in science education has been acknowledged for its potential to cultivate scientific literacy in students by engaging them in critical discussions around socially relevant scientific issues (Sadler, 2011; Zeidler & Kahn, 2014). Many education reforms worldwide have incorporated SSIs in science education. India's recent National Education Policy (NEP) 2020 also emphasises integrating critical community issues into curricula, paving the way for SSI-based teaching (Section 4.23, p. 15, NEP 2020). However, despite teachers' interest in SSI-based teaching, there is also a hesitancy among teachers to incorporate SSIs in regular teaching due to their inherent complexities and multidisciplinary nature (Anagun & Muhammet, 2010; Lee et al., 2006). Studies have reported teachers' challenges in balancing scientific and social components (Minken et al., 2021), grappling with their own

[1] Socio-scientific issues (SSI)s are complex, multidimensional, and controversial problems that intertwine with science and technology (S&T), and often possess moral and ethical dimensions (Zeidler et al., 2005).

beliefs and biases in dichotomic situations (Parr, 2013), meeting instructional demands from peers and school systems and assessing students' SSI-specific skills (Nielsen, 2020; Nordqvist & Jidesjö, 2023), relinquishing control to students during SSI discussions and carving sufficient instructional time for SSI-based pedagogy (Lee & Yang, 2019; Pitiporntapin et al., 2018).

Additionally, teachers have reported the lack of relevant training resources for SSIs and the prioritising of disciplinary knowledge by existing teacher education programs (Lee et al., 2006; Tidemand & Nielsen, 2017). Consequently, a gap between policy aspirations and classroom practices for SSIs indicates the need for specific training interventions for teachers to build their competencies for SSI-based instruction. Recent research emphasises that professional development programs which are reflective and situated within authentic contexts can support teachers in appreciating the socially embedded nature of science (Lee et al., 2023; Zhang & Hsu, 2025)

In response to this situation, we designed a prototype short-term intervention program to orient science teachers towards SSI-based pedagogy through co-constructive experiences. We analysed participant teachers' engagement with the intervention program in detailed case studies, such that the knowledge is useful for further instilling a research-based design for TPD programs for larger groups of teachers in similar settings. By supporting teachers with the knowledge and skills for SSI-based instruction, the intervention program aimed to enhance teachers' competence to organise SSI-based discussions, aligning with the evolving educational landscape and societal needs. In our study, we acknowledge teachers' high learning spirit and reflexivity, which is also understood as an important characteristic for a healthy adaptation and implementation of SSI-based pedagogies.

1.1. Theoretical Perspectives: Co-construction and Pedagogical Content Knowledge

In teacher education, a constructivist approach suggests that teachers co-construct knowledge through collaborative activities with fellow teachers, experts, students, etc. Similarly, teachers are supposed to be reflective about their teaching practices and beliefs (Zeidler & Sadler, 2008) and be aware of the environment where the activities are planned. Moreover, teachers must consider students' prior knowledge, interests, and learning experiences while designing instructional approaches (Zeidler, 2014). By engaging in meaningful interactions with stakeholders and reflecting on their own practices, teachers can continuously refine their pedagogical content knowledge, PCK – a specialised type of knowledge about teaching specific content to students effectively and meaningfully (Shulman, 1986). This study views teachers' PCK as transformative and situated, recognising that continuous reflection and collaboration shape and refine teachers' understanding of teaching within the specific sociocultural context.

Magnusson et al. (1999) proposed a comprehensive model of PCK for science teaching, comprising five key components: teachers' orientations to science teaching encompassing their beliefs and approaches to science education; their knowledge of students' understanding of science and recognition of common misconceptions and learning difficulties; their understanding of the science curriculum to align their instruction with curriculum standards and real-world contexts; their knowledge of instructional strategies and representations including familiarity with a range of teaching methods and resources to engage students meaningfully, and their expertise in employing various assessment tools and strategies to evaluate student understanding effectively. Overall, these components of PCK allow an observational and analytical lens to explore teachers' enactment of SSI-based discussions in their classrooms.

While these key components of PCK largely fit any science course instruction, according to Lee and Yang (2019), PCK for SSIs can be topic-specific. Moreover, with the inherent complex and multidisciplinary nature of SSIs, PCK is even more critical in maintaining a balance between science content and the social component. Teaching SSI requires a shift in classroom culture, where teachers design such learning experiences that encourage students to deliberate on scientific concepts from multiple perspectives as well as reflect on their own stances (Zeidler et al., 2019). For this purpose, teachers need to critically reflect on their own assumptions and instructional practices to improve their understanding of the content, teaching methods, and anticipate challenges. Recent research emphasises that such reflective, situated, and dialogic approaches are essential for fostering teacher identity transformation and supporting innovative pedagogies like SSI-based teaching (Talafian et al., 2025). In short, teachers are required to modify and develop their existing PCK to align with the demands of SSI-based approaches in science education.

2. METHODS

This study integrates co-construction and PCK in its intervention design. The intervention design is influenced by the first author's first-hand experience of developing an SSI-based module, based on the needs assessment of participant teachers and existing literature. The two teacher participants of the intervention stage were engaged in exploration and reflection on SSIs and developed some exemplary SSI-based learning modules. Two working research questions guided the study.

1. What are the major challenges and issues faced by teachers while designing SSI-based learning modules in the intervention program?
2. What are the resources and successful strategies that assist teachers in designing and implementing SSI-based learning modules?

2.1. Participants and the Setting

This study used a qualitative case study approach, and the teacher participants were selected through purposive sampling. We aimed for experienced secondary science teachers with more than 5 years of teaching experience who had an interest in the Science-Technology-Society-Environment (STSE) perspective of science education. A total of nineteen teachers were contacted by email, of which 5 teachers (25% of the initial sample) responded to the request and completed an open-ended questionnaire. With some follow-up on the questionnaire, two teachers (8% of the initial sample) agreed to commit to the study. Based on the demanding nature of the study and case study format, we considered going ahead with the 2 teachers. We used the pseudonyms Ruby and Surabhi for these two teachers.

Ruby, with a Biology master's and nearly eight years of experience teaching elementary and secondary students, currently teaches in a school with students from lower socioeconomic backgrounds. She expressed her interest in focusing on inclusivity and relevance in science education and aligned this with STSE perspectives and addressing real-world issues in teaching. Surabhi, with a master's degree in Chemistry, has a decade of teaching experience, mainly teaching secondary and higher secondary students. Surabhi emphasised critical thinking, argumentative abilities, and societal awareness in teaching and also led an eco-club to promote environmental issues at her school.

Both teachers in the initial follow-up showed an inclination towards holistic student development and integrating scientific knowledge with everyday experiences and societal issues. Most of the interactions with the teachers discussed in this paper happened during the COVID-19 pandemic, resulting in a shift to online meetings.

2.2. Methods of Data Collection and Data Analysis

Interactions with the teachers spanned over a period of around three months and were primarily conducted using online platforms. The data was collected at multiple stages to develop a comprehensive understanding of teachers' evolving understanding of SSI-based pedagogy and their experience of co-developing the SSI-based modules. Firstly, semi-structured interviews were conducted before the intervention to explore teachers' initial perspectives and preparedness. Intervention sessions were audio- and video-recorded (wherever possible) to document the evolving engagement of the teachers. Reflection sessions provided teachers with insights into their challenges and successes. Detailed field notes were maintained to document key observations. Additionally, teachers' written reflections offered personal insights into their experiences and pedagogical evolution. Moreover, the SSI-based modules themselves were analysed to discern the integration of SSIs, content knowledge, and pedagogical strategies, representing the teachers' application of PCK. This comprehensive approach provided a holistic view of the teachers' journey and enriched the findings through the triangulation of diverse data sources.

The qualitative analysis of the data was guided by the five key components of the PCK framework discussed earlier. Initially, important segments of the data were identified, corresponding to the challenges faced by the researchers and teachers, strategies and resources employed, and components of the PCK framework. These segments were transcribed and further analysed to uncover recurring themes and sub-themes. Sub-themes were further explored to provide a more detailed examination of the data, capturing

specific details and variations related to different PCK components. Instances where the researchers struggled, or teachers faced some challenges were systematically explored. For instance, under the 'Orientation to SSI-based teaching, researchers noticed a struggle among teachers to convey the value-laden aspect of SSIs. The analysis of this segment focused on (if) specific strategies were employed and how. Some observations were made towards including discussions around an SSI with a prominent value-laden aspect using probing and prompting techniques. A similar analysis was done for different PCK components.

Throughout the analysis, efforts were made to maintain objectivity and ensure that interpretations were firmly grounded in the data itself. To enhance trustworthiness and validity, the preliminary findings were shared and discussed with an expert in the field, whose valuable insights and suggestions were incorporated into the process, contributing to the refinement and accuracy of the identified themes and sub-themes.

2.3. The Intervention Program

The journey of the development of the intervention program was guided by the researchers' own experiences of the development and implementation of the SSI-based module. The first author developed and implemented an SSI-based learning module on groundwater issues, titled 'Groundwater- It's in danger, so are we!', with grade-9 students (Kaushik et al., 2022). This exercise served the purpose of gaining valuable insights for future interactions with teachers. Moreover, by gaining an insider's perspective on SSI-based learning, the researchers aimed to better empathise with teachers, effectively address their concerns, and provide practical guidance and support. Additionally, the first author also performed a needs assessment to identify what the intervention design would involve based on an insight into teachers' perspectives on science education, their teaching practices, and gathering a sense of their beliefs, goals, and approaches to science teaching, as well as their views on integrating SSIs into the curriculum.

During this need assessment, teachers expressed a commitment to developing students' science content and process skills, as evident in their responses stating, "*Science education is not merely restricted to the study of the established laws, scientific principles, and theories; rather it is to develop scientific temperament in the learners*" (Surabhi). Teachers also emphasised the importance of establishing connections between science and everyday experiences, with one teacher stating that science education involves "*Making students understand the importance of science in daily lives*" (Ruby). It also appeared that the teachers believed that S&T are value-neutral and that any issues are created due to their misuse. Ruby's articulation, '*risks due to inappropriate use of technology such as the internet, mobiles, etc.*,' suggests that the misuse of technology is a humanised choice of practising S&T.

The teachers recognised the significance of incorporating SSIs into science education to create awareness and increase student engagement. They acknowledged that SSIs allow students to bring forth their own opinions, develop analytical skills, and think scientifically. Ruby remarked, "*Incorporation of these issues might enhance the participation of students in class. Every student has something to say about these issues, so it increases their participation.*"

At the same time, the discussion also revealed teachers' hesitancy to engage in in-depth discussions on certain SSI topics due to time constraints and concerns about the sensitive nature of the issues. Despite recognising the importance of SSIs, they viewed these as better suited for disciplines like social studies. Moreover, teachers preferred to stick to science textbooks for lesson planning, which highlighted the importance of aligning the intervention program with the existing curriculum. Based on the need assessment, teachers' preference for making science content more accessible and relatable through contextualisation became a key idea, while other observations informed the nitty-gritty of the intervention design.

3. RESULT AND ANALYSIS

As the research data is in the form of the researcher and participant teachers' reflections, we showcase it alongside the analysis. The intervention introduced teachers to some concepts and theoretical underpinnings of SSI-based education. The analysis explores the ways in which teachers felt supported by practical tools and strategies to organise SSI-based instruction.

3.1. Development of Intervention Program Design

The design of the intervention program is a result of researchers' own reflections about what can constitute a good strategy for orientation and structuring co-constructive experiences for teachers after detailed, deliberate exercises of need assessment and self-capacity building for SSI-based module development and facilitation; therefore, the intervention design is also discussed here.

The intervention program aimed to develop teachers' SSI-specific PCK to enable them to design, implement, and assess SSI-based lessons effectively. It consisted of two components: 1) orienting teachers towards an SSI-based approach with pre-developed SSI modules and some useful SSI instruction-associated resources, and 2) providing co-construction experiences for teachers to create SSI-based learning modules. For the orientation, the SEE-SEP model was introduced to teachers. The model served as a guide for the selection of SSI topics by recognising its scope to cover social, environmental, economic, scientific, ethical, and policy dimensions of an issue (Rundgren & Rundgren, 2010). Additional resources included the PARRISE[1] (Promoting Attainment of Responsible Research and Innovation in Science Education) project report, STEPWISE[2] (Science & Technology Education Promoting Wellbeing for Individuals, Societies & Environments) resource guide, Zeidler and Kahn's 'It's Debatable' book, and the researcher developed an SSI-based module titled 'Groundwater-It's in Danger, So are We!' (Kaushik et al., 2022). PARRISE emphasises SSIs for learning, providing guidance and case studies. STEPWISE offers model activities for teaching SSIs,[2] while 'It's Debatable' provides SSI-based lessons for scientific literacy.

Throughout the intervention program, each teacher collaboratively planned and designed an SSI-based learning module with the first author. The teachers contributed their practical knowledge and insights from their classroom experiences, ensuring the learning modules were suitable for regular classroom implementation. Multiple cycles of planning, designing, and reflecting occurred, leading to valuable insights for both the teachers and the researcher. The details of the training program are presented in Table 1.

Table 1. Session Details for Intervention Program

Sessions	Session Objectives	Main tasks
Preliminary discussion	Explore teachers' orientation to science teaching and SSI-based teaching	Facilitate discussions on participants' teaching experiences; Self-reflection exercises on personal perspectives; Sharing of relevant literature on SSIs.
1. Understanding SSIs (orientation phase)	Explore the significance of SSIs in contemporary science education. Grasp the multifaceted nature of SSIs and their relevance to real-world contexts.	Exploration and reflection activities to understand what characterises an issue as an SSI; Discussions on the key components of SSIs
2. Exploring SSI-based Modules (orientation phase)	Study existing SSI-based modules and related resources; Identify components crucial for effective SSI-based teaching.	Examination of sample SSI-based modules and analysis of module components and pedagogical aspects.
3. Identifying suitable SSI	Finalise SSI for intervention Develop module objectives	Selection of appropriate SSIs. Developing clear objectives
4. Development of Module	Develop module activities and tasks. Plan students' assessments within the SSI context.	Developing activities for SSI-based modules; Planning assessments that align with SSI objectives.
5. Reflecting on the developed module	Discuss and modify the developed SSI module based on insights gained during the intervention program.	Piloting and Refinement of SSI-based modules;

[2] PARRISE Research Project Report - Deakin STEME. can be accessed from https://deakinsteme.org/wp-content/uploads/2019/08/PARRISE-Research-Project-Report.pdf

Anticipate implementation challenges and explore potential solutions	Brainstorming challenges in implementing SSIs; Collaborative problem-solving exercises.

During the intervention program, some tinkering around SSI-specific instructional strategies happened. While the teachers already had some familiarity with these strategies, the tinkering provided opportunities for them to reflect on their effective use within an SSI framework. For instance, one such strategy was 'Probing', aimed at facilitating in-depth exploration of SSIs. During sessions, teachers were encouraged to delve into different dimensions of SSIs, including their value-laden aspects. On one occasion, Ruby shared her experience of discussing 'water pollution' in her classroom, emphasising general impacts and potential solutions. However, she hadn't explored the cultural and religious dimensions, like pollution caused by 'Murti-Visarjan or idol immersion in water' rituals.

> *Ruby: I have really not directly discussed the pollution caused by these rituals with my students. Discussing such issues could be sensitive.*
>
> *Researcher: What do you think…… can these discussions be useful for students?*
>
> *Ruby: Discussing these aspects and exploring sustainable ways to celebrate these festivals could really make students motivated in the classroom and create awareness among them. Many campaigns are going on which encourage environmentally friendly idols.*

With the researcher's probe, Ruby reflected on the multifaceted nature of the issue, recognising its broader implications. Similarly, Surabhi's discussion on the 'mining' topic focused on environmental and health impacts, but probing led her to consider ethical aspects like child labour and community displacement. This exercise broadened their perspectives and highlighted the complexity of SSIs.

'Mind-mapping' was another strategy used to visualise the complexity of SSIs. Teachers were encouraged to create mind-maps of SSIs of their choice using the SEE-SEP framework as a reference. Ruby and Surabhi mapped out various dimensions and stakeholders related to issues like 'chemical fertilisers' and 'mining', respectively. Similarly, the use of 'media articles' was introduced as another pedagogical strategy to connect classroom learning with real-world issues. Media articles are recognised as useful teaching resources in SSI-based education (Dimopoulos & Koulaidis, 2003) because they link classroom learning with real-world contexts. Teachers discussed how media articles could enhance students' understanding and engagement. Surabhi noted that analysing media articles could improve students' media literacy skills, while Ruby saw value in establishing connections between real-life experiences and school science. Both recognised the significance of such discussions in raising awareness among students.

Lastly, 'perspective-taking' strategies were used to explore SSIs from diverse viewpoints, particularly focusing on ethical and moral dimensions. For example, discussions on embryonic research and surrogacy prompted teachers to consider different perspectives, such as those of scientists and surrogate mothers. Ruby reflected on the ethical implications of embryonic research, acknowledging the moral dilemmas involved (excerpt given below).

> *As a scientist, I would say that embryonic research should be supported as it may help so many people… by developing treatments for various diseases. But, on the other hand, as a donor, it would be difficult; there will be guilt, moral issues, like harming a human life, destroying or harming embryos for research purposes… raises ethical questions. As life is sacred.*

Similarly, Surabhi contemplated the emotional and societal implications of surrogacy, recognising the complexity of decision-making beyond scientific aspects. These discussions enabled teachers to navigate the intricate landscape of values and ethics associated with SSIs, enhancing their understanding and awareness.

The design of the intervention recognised teachers as active partners in creating knowledge and used their insights and experiences to shape the program further.

3.2. Implementation of the Intervention Program

This section focuses on analysing the process of teachers' adoption of SSI-based pedagogy. As a result of the intervention program, Surabhi and Ruby underwent the exercise of co-construction of modules. Surabhi developed an SSI module on fossil fuels, while Ruby opted for the topic of COVID-19.

Surabhi's module on fossil fuels involved discussions on energy usage, sources of energy, a mathematical calculation for estimating domestic energy usage, and a reflection on media articles. Through these activities, students were encouraged to discuss various pros and cons of the use of fossil fuels and reflect on whether limiting our dependence on fossil fuels is possible, and in what ways. Ruby's module on COVID-19 involved capturing students' perceptions about the COVID-19 vaccine, and how the pandemic impacted their lives, and extending the discussions through role-play activities to understand their decision-making about the COVID-19 vaccine, and the general understanding of the vaccination process.

The analysis situates the teachers' experiences of module development and facilitation under the lens of five main PCK components (discussed earlier), so the results are also organised thematically according to these components.

3.2.1. Orientation to SSI-based Science Teaching

Before finalising the SSI for module development, teachers engaged actively with various potential SSIs, from climate change and surrogacy to stem cell research. Teachers explored the key characteristics of these issues, including the SSIs being contentious (controversial), multidimensional (involving multiple facets), open-ended (lacking clear-cut solutions), value-laden (influenced by ethical and societal values), and subject to ongoing inquiry (continual investigation and debate).

As teachers explored SSIs, several themes emerged (Figure 1). Firstly, there was a recognition of the complexity inherent in SSIs. Teachers acknowledged the multifaceted nature of these issues and expressed the importance of exploring them in their classrooms. For instance, Ruby remarked on the diverse aspects of water pollution beyond environmental concerns, emphasising the need for students to observe local practices and explore eco-friendly solutions.

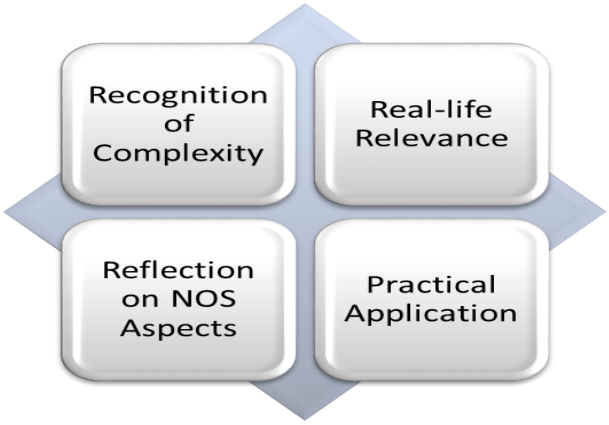

Figure 1. Themes Identified from Teachers' Interaction with the Provided Resources and the Researcher

Secondly, teachers reflected on the nature of science (NOS) aspects related to SSIs, such as their being value-laden and involving intellectual scepticism. Teachers emphasised the significance of critically evaluating scientific evidence. Developing scepticism posed a challenge, despite its importance in science education frameworks (NEP, 1986, 2020; NCF, 2005, India). Through discussions on topics like climate change and stem cell research, teachers remarked on the dynamic nature of scientific knowledge and the value of exploring contrasting views. Surabhi stated, "*Discussing these issues and exploring contrasting views would help students understand the nature of science.*" Ruby also highlighted the ongoing debate surrounding climate change, underscoring the need for students to critically evaluate evidence from different perspectives.

Thirdly, teachers recognised the real-life relevance of discussing SSIs, noting their significance to students' daily lives. They appreciated the opportunity to engage students in discussions on issues like product safety and global challenges, recognising the potential for students to make informed decisions.

Finally, teachers reflected on the practical application of SSI-based approaches in their teaching practice. They recognised the feasibility of integrating SSI-related activities into their lessons and appreciated the structured approach provided by available resources. Ruby stated, "*I can see how these discussions can be used in my regular lessons. It's not as complicated as I thought, and it can make science more engaging for the students."*

Through reflective activities and open dialogues, teachers' deeper appreciation of the complexities in SSIs and their openness to infuse their classrooms with real-world relevance and critical inquiry were evident.

After the orientation exercise, when Ruby and Surabhi were tasked with selecting topics for their SSI-based modules, both drew from their prior interests, academic training, and teaching orientations, but were open to developing the module to invoke critical inquiry in the classroom. Ruby's choice of 'COVID-19' reflected her commitment to activism and citizenship orientation, aiming to engage students in exploring the pandemic's societal impacts and fostering awareness of their roles and responsibilities. In contrast, Surabhi's selection of 'Fossil Fuel' showcased her focus on the 'Nature of Science and Technology' orientation, prompting students to reflect on the pros and cons of fossil fuel usage and encouraging informed decision-making.

3.2.2. Knowledge of Science Curriculum

As mentioned previously, it was noted that there was a hesitation among teachers in accepting SSI's due to a lack of curricular connections. To address this, we explored the relevance of SSIs within the current science curricula, anticipating that recognising this relevance would motivate teachers to potentially adopt the SSI-based approach. Central to this effort was investigating how SSIs aligned with the objectives of science education.

Teachers identified SSIs from their science textbooks and created mind maps of these. Ruby identified issues such as pollution, resource scarcity, deforestation, technology misuse, and chemical fertilisers. Surabhi listed pollution, global warming, GM crops, and mining as SSIs. Additionally, they were asked to reflect on the fulfilment of science education objectives and competencies. This approach aimed to encourage systemic thinking by revealing interconnections between various systems (social, environmental, economic, etc.).

Through this activity, both teachers recognised the potential alignment of SSIs with science education objectives, including the development of critical thinking and engagement with real-world complexities. However, Ruby expressed concerns about the feasibility and student challenges, prompting further discussion and exploration of SSI-based curriculum materials to address these reservations. Meanwhile, Surabhi acknowledged the scope of SSIs in current curricula and reflected on their potential to sensitise students and promote critical thinking.

> *Surabhi: I now feel that I should discuss more about it in class, as mining is more than just extracting valuable metals; it involves environmental and societal concerns. Consider the impact on the miners themselves, communities displaced, or children in labour work. These should be explored in our classrooms to sensitise them, exploring the issues with mining and sustainable practices.*
>
> *Discussing these issues and exploring contrasting views would help students in understanding the nature of science…*

While developing learning objectives for their modules, Ruby and Surabhi corresponded with the higher-order cognitive skills from Bloom's Taxonomy, aiming to foster deep thinking and engagement. Both focused on students' affective as well as psychomotor domains. Ruby's objectives for her COVID-19 module encompassed a wide range of aspects, from understanding contagious diseases to exploring socioscientific dimensions and promoting civic engagement by creating awareness in their communities through posters and conducting interviews. Objectives for Ruby's learning modules were:

> *To explore various media resources to learn about COVID-19; To develop an understanding of contagious diseases using the example of COVID-19; To explore socioscientific aspects related to COVID-19; To explore*

the impact of COVID-19 on different sections of society.; To create awareness about COVID-19 in their neighbourhood.

Surabhi aimed to engage students in critical analysis of fossil fuel usage, with objectives spanning summarisation, analysis, and evaluation of the pros and cons. Her objectives were designed to encourage students to:

Summarise the issues arising due to the use of fossil fuels; Analyse the pros and cons associated with the use of fossil fuels; and Become sensitive to the usage of resources based on fossil fuels

Both teachers sought to encourage critical thinking, exploration, evaluation, and societal awareness through their modules. Ruby engaged students in creating documentaries to explore perspectives on COVID-19 and posters to explore and promote COVID-19 safety. Surabhi guided students in reflecting on the societal and environmental impact of fossil fuel reliance. Both emphasised a constructivist, student-centred approach that had been emphasised during interactions with the researcher and in the SSI-based resources.

3.3.3. Knowledge of Students' Background

The two teachers in this study possessed substantial teaching experience and were familiar with their students' backgrounds. During the initial discussions about their class planning, both emphasised the importance of assessing students' prior knowledge and connecting new content with the curriculum and everyday experiences. Ruby, for instance, emphasised integrating her SSI-based module on COVID-19 with the existing science curriculum. She revisited concepts like communicable diseases and health from previous lessons. By reminding students about who is considered healthy, she encouraged them to reflect on how COVID-19 has impacted not only physical health but also social and mental well-being, helping connect the new information to broader health issues and their effects on individuals and communities.

Knowing the students' backgrounds, teachers anticipated the potential difficulties, such as comprehending media articles, identifying stakeholders, and considering different aspects of SSIs. For example, Ruby was concerned that her students might struggle with the complex language in media articles. To address this, she simplified the articles, breaking down technical terms and translating them into the Hindi language for better comprehension. Additionally, she organised role-play activities that helped in identifying stakeholder perspectives. She stated,

Even while planning, I was aware that students would face difficulty in identifying scientific concepts and stakeholders; that's why I emphasised providing examples. During the session, I also explained the whole task for students with examples to guide them.

Conversely, Surabhi was worried about the credibility of the sources of the articles her students would select. To mitigate this, she instructed her students to use well-established, reputable sites and advised against relying on unverified sources.

Ruby and Surabhi shared concerns about their students' readiness for SSI-based discussions. To ensure that students were adequately prepared, they designed home assignments. These assignments required students to explore media articles and gather pertinent information online. By doing so, they aimed to address the gap between students' existing knowledge and the complexities of SSIs.

3.3.4. Knowledge of Science Instructional Strategies

The implementation of the SSI-based approach necessitates a shift in the classroom culture. It requires reorganising learning materials and adopting new instructional strategies, and hence can be challenging for teachers. (Hancock et al., 2019; Sadler et al., 2017).

Our data also indicated some of these challenges, along with how teachers resorted to different ways for mitigating them. Some of these strategies are listed below:

Seeking Guidance: Ruby and Surabhi recognised the need for support in shifting to SSI-based teaching. Ruby sought to model her module after the groundwater module, developed by the first author (Kaushik et al., 2022). She stated,

> *This is way more difficult than I thought. I think I will develop my lesson similarly to yours (GW module). If that's okay. It would be helpful to have a template for this.*

Whereas Surabhi used resources made available during orientation to shape her module. She acknowledged,

> *Planning lessons around SSIs is different from what we're used to. So, I took help from the internet (STEPWISE) and the book (Zeidler & Kahn's 'It's Debatable', 2014) to get some idea of the tasks, then I decided to keep discussion as the main approach, and reading the article and mind-mapping as the main activities for the students.*

Acknowledging Complexity: Both teachers acknowledged the complexity of designing SSI-based modules. Ruby struggled with determining the content and scope, reflecting a common teacher challenge of balancing comprehensiveness with manageability. Surabhi, on the other hand, focused on the multidimensional nature of her issue. She acknowledged in the beginning that managing discussions to cover all these dimensions might present a challenge. Her observation pointed to the intricate interplay of various aspects within SSIs and the need to ensure that students gain awareness of these complexities, reflecting her efficacy as a teacher.

> *Surabhi: Since these issues are multidimensional, it will be a challenge to manage the discussion so that all these dimensions, SEE-SEP dimensions, are covered.*

Ruby used structured tasks and group presentations to manage various aspects of COVID-19. Surabhi opted for a more open class discussion format to engage students in exploring the contentious aspects of issues related to fossil fuels. This approach recognised the dynamic nature of SSI-based discussions, allowing students to delve deeper into the complexities as they arose during the conversation.

Both teachers' reflections exemplify their recognition of the multifaceted nature of SSIs and the challenges that come with translating this complexity into effective classroom experiences. While Ruby leaned towards a structured approach, Surabhi embraced the organic nature of SSI discussions in her classroom, demonstrating the diversity of strategies teachers can employ to address SSIs.

Balancing Scientific Content and Societal Context: Literature suggests that teachers struggle to balance scientific and societal aspects in SSI-based modules (Minken et al., 2021). Teachers were asked to pay attention to balancing scientific content with societal, ethical, and real-world implications. Ruby used a structured approach for her module, starting with homework that prompted students to reflect on COVID-19's impact on their lives, followed by in-class activities like mind-mapping to explore both scientific and societal aspects. This ensured scientific concepts were integrated with real-world concerns.

Surabhi focused on fossil fuels, first addressing students' conceptual understanding and environmental impacts, then exploring societal consequences through class discussions. Her method encouraged critical analysis of scientific content in real-world contexts.

Integration of Media and Real-World Context: Recognising students' exposure to media, both teachers incorporated real-world sources into their modules. Ruby emphasised the connection between classroom content and current events, while Surabhi leveraged students' interest in internet surfing to explore relevant issues. She remarked,

> *Students might find exploring articles interesting. My students like to discuss current issues, anything other than the book. Students have become more tech-savvy, and they spend more time on the Internet. They enjoy surfing the Internet. We can put their time to good use through this exercise. They can relate to what's happening outside the classroom.*

3.3.5. Knowledge of Assessment

Assessment plays an important role in the teaching-learning process, and its significance further increases when considering the relatively novel approach of SSI-based discussions. In this context, both

teachers demonstrated familiarity with formative assessment techniques such as questioning and analyzing student input as part of their instructional strategies. They articulated various assessment methods for SSI sessions, including questioning to gauge understanding, observing students' contributions, evaluating presentations, and peer evaluations. For example, Ruby mentioned,

> *I have been using more formative assessment techniques, like group presentations and quick quizzes. It helps me see where my students stand. And it also makes students attentive, they know ma'am can ask any question anytime.*

However, the effectiveness of assessment requires an understanding of what facets to evaluate. SSI-based pedagogy introduces additional layers of assessment challenges, such as assessing the development of critical thinking and ethical decision-making skills in students as they grapple with multifaceted SSIs, and evaluating students' adeptness at identifying biases and diverse perspectives within SSI discussions. Furthermore, evaluating students' grasp of the interconnectedness between scientific, societal, and ethical dimensions within an SSI adds another layer of complexity to the assessment process.

Addressing these nuanced assessment challenges requires strategic approaches. The teachers were encouraged to contemplate the facets they would assess in the context of SSIs. Ruby aimed to gauge students' grasp of the issue, their ability to analyse SEE-SEP dimensions, and the impacts on diverse stakeholders, while Surabhi's assessment objectives centred on assessing students' understanding of the inherent tensions tied to fossil fuel use and their exploration of SEE-SEP dimensions. She remarked,

> *Discussion on these issues would be an interesting experience for students. They would be sharing their opinions rather than facts. So I will focus on how informed their opinions would be, whether they are 'backing their claims with some evidence' or just stating their opinions. I will also give them some project work as home assignments for assessment. I can also use their mind-maps.*
>
> *I will tell my students that these classes will be recorded and graded. So that they take it seriously.*

This highlights the dynamic interplay between the specific SSI topics and the assessment objectives. Ruby's module prioritised societal implications, while Surabhi's module focused on navigating complex dilemmas, encompassing scarcity, dependency, and adverse consequences. Both teachers acknowledged that assessments encourage active student engagement, so they both decided to formally grade homework assignments to foster enthusiastic involvement.

4. DISCUSSION

The current study adopted the PCK framework as an analytical lens for effectively elucidating two teachers' experiences with SSI-based pedagogy in Indian science classrooms. Previous literature highlights that science teachers tend to exhibit reservations when it comes to adopting the SSI-based approach as a regular instructional approach (Lee & Witz, 2009). This resistance can be better understood through the lens of teacher professional identity and underlying professional beliefs. The research in resource-constrained contexts (Mandina, 2024) shows that exam-oriented systems and institutional cultures influence teachers' pedagogical choices, making it difficult for teachers to adopt approaches that demand dialogic and critical engagement, such as the SSI-based approach. Furthermore, this hesitancy is compounded by the demanding nature of the SSI-based approach and teachers' often absolutist perspective on science, where science is perceived as fixed content rather than a socially negotiated enterprise, rendering it difficult to allocate equal importance to STSE/SSI perspectives alongside scientific disciplinary knowledge (Kilinc et al., 2017). A study by Badeo and Duque (2022) reported a large effect (d=1.08) for SSI-based pedagogy on student outcomes, yet implementation remains limited due to these barriers, indicating that addressing teacher hesitancy requires not only teacher training but also structural reforms.

The study presented here is a segment of a broader PhD project depicting teachers' experiences of the development and implementation of SSI-based activities. Given the substantial investment of time and effort required on the part of teachers in SSI-based instructions and also the nature of this qualitative education research, an intricate sample was justified. In this study, we worked with two experienced and committed teachers with a proclivity towards STSE perspectives within science education. Research highlights the significant impact of motivation on learning outcomes, with teachers' beliefs and values playing a pivotal role in shaping their decisions regarding SSI-based discussions (Lee & Witz, 2009). While

teacher motivation is crucial, Datnow and Park (2018) advocate that teachers interpret new pedagogies through the lens of their existing professional identities and available institutional support. A study by Nida et al. (2020) observed that Indonesian teachers, though motivated, lacked SSI-related teaching resources and struggled to translate motivation into practice. These findings aligned well with Hancock et al. (2019), highlighting the significance of concrete support and adequate professional teacher development to develop requisite PCK for SSI-based approaches.

An intriguing progress in the teachers' orientation towards SSI became evident through the course of interactions. According to Chang and Park (2020), a teacher's orientation to science teaching and instructional strategies interlinks closely with various dimensions of PCK. In our data, initially, the teachers perceived SSI as a mere tool to spark students' interest and enhance accessibility to science disciplinary knowledge, a perspective termed as an instrumental view of SSI (Tidemand & Nielsen, 2017). However, as the teachers engaged in reflective discussions regarding the goals and objectives of science education as prescribed by NCF-2005 and NEP 2020, coupled with exploring the nature and affordances of SSI-based approaches, their perception of SSI transformed. Their learning modules began to pivot around the chosen SSI, positioning it at the core. For instance, Ruby narrowed her topic from 'communicable diseases' to 'COVID-19', anchoring it to a real-life issue which students themselves have closely experienced in recent times, and structured the module content such that students have multiple opportunities to share their experiences, voice their opinions, and feel their societal existence and agency while talking about control measures. Similarly, Surabhi titled her lesson 'Fossil fuels: A Necessary Evil?', accentuating the issue's contentious nature. This transition highlights that teachers were able to develop SSI-based learning modules that moved beyond contextual tools for learning science content, instead embedding science within its social fabric. These findings highlighted the significance of reflective dialogue and collaboration in shifting teachers' perception of SSIs from mere engagement tools to the central component of their teaching. This aligns with Zhang and Hsu (2022), who assign such shifts as identity development processes catalysed by sustained reflection and peer collaboration. Durak and Topçu (2025) further emphasised that professional learning communities are crucial for building teacher agency in resource-constrained contexts.

Nevertheless, the teachers' persistent conviction that science is inherently value-neutral surfaced as a deeply rooted one. Their belief in the neutrality of S&T and attributing issues to their misuse rather than their socially embedded nature highlighted an ongoing challenge. Inculcating scepticism, a component of the 'Nature of Science', remains a challenging task (Bryce & Day, 2014), rarely addressed within formal science curricula. In the present study, continuous reflective practices and dialogic engagement enabled teachers to begin to appreciate the SSI perspective by exploring multiple dimensions of SSIs. This is in alignment with the situated cognition perspective, which emphasises that such shifts are shaped by social and cultural contexts where participation in authentic practices and collaborative reflection foster learning and professional growth (Talafian et al., 2025; Lave & Wenger, 1999). Recent studies also confirm that socio-ethical and reflective professional development help teachers in understanding the socially embedded nature of science (Lee et al., 2023; Zhang & Hsu, 2025). However, their belief in science's value-neutrality still surfaced at times in the present study, highlighting the need for prolonged engagement and critical reflection (Tsaliki et al., 2024).

Interestingly, both experienced teachers in this study, despite their strong science teaching backgrounds, encountered difficulties in devising SSI-based modules. This struggle indicates the complex nature of this pedagogical shift. During the module co-construction, teachers searched for templates to initiate the module design; this act further echoes the need for support articulated in the literature (Hancock et al., 2019; Sadler et al., 2017). In this study, teachers drew from the Ground Water module developed by the researcher, the instructional framework by Sadler et al. (2017), Zeidler and Kahn's 'It's Debatable' (2014), Bencze's (2017) STEPWISE resources, and Rundgren and Rundgren's SEE-SEP framework (2010). These findings are supported by research from Thailand and Indonesia, which shows that sustained, collaborative Professional Development enables teachers to develop SSI modules effectively but also reveals teachers' struggles with balancing societal and content emphasis (Pitiporntapin et al., 2018). Even after designing learning modules, one teacher, Ruby, initially grappled with addressing students' unique queries and responses. She apprehended that students might introduce arguments and opinions rooted in their experiences, sometimes amalgamating personal experiences with scientific information. This poses a challenge for teachers accustomed to closed-content teaching, anchored in predetermined correct answers, and echoes findings from literature where teachers expressed uncertainty in managing SSI-based discussions

and prefer content coverage over dialogic inquiry (Lee et al., 2006; Lee & Yang, 2019; Nordqvist & Jidesjo, 2023).

In this study, both teachers exhibited a keen understanding of their students and the dynamics of their classrooms, a critical factor according to Kagan (1992) for teaching-learning efficacy. Research also suggests that familiarity with students' backgrounds aids in selecting SSIs that resonate personally with students, consequently shaping suitable learning experiences (Saunders & Rennie, 2013). In our study, Ruby used background information on communicable diseases and health to contextualise her module on COVID-19, helping students connect new material to prior lessons. Similarly, as discussed earlier, this approach effectively aligned with students' needs and enhanced their understanding of both scientific concepts and real-world implications. The findings also revealed that teachers found it difficult to provide the necessary space for various dimensions of the concerned SSI. For instance, they struggled to cover essential scientific knowledge and focused more on the societal aspects. However, with their own reflection on the learning modules and reflective interactions with the researcher, they incorporated necessary opportunities for students to delve into the scientific as well as societal aspects of the issue. This echoes the findings of Minken et al. (2021), highlighting that teachers often grapple with striking a balance between scientific and other dimensions of SSIs.

According to Hammond and McLaughlin (2011), effective training programs offer a learning experience that encompasses a clear vision of distinct practice, models of intended instructional strategies, and opportunities for application and reflection. In this study, the interactions during orientation were carefully designed to allow teachers to perceive SSI discussions through the lens of learners while also navigating these discussions as educators. Analysing SSIs from a learner's perspective first equipped the teachers to understand the intricate nature of these issues, in turn aiding the design of tasks tailored for students in similar SSI units. This approach enabled them to anticipate challenges students might face and provided opportunities for reflective practices.

This study further affirms that collaborative module development can reframe teachers' roles from content-deliverers to co-designers and facilitators, supporting identity negotiation and situated learning (Polizzi, 2021; Lave & Wenger, 1999). It highlights the need for teacher professional development models that embed sustained collaboration, reflective practices, and context-specific resources. (Pitiporntapin et al., 2018).

5. CONCLUSION

Our findings emphasise the need for a structured framework to guide teachers in developing SSI-based learning modules, especially given the challenge of deviating from traditional teaching methods in Indian classrooms. Both Ruby and Surabhi acknowledged that SSI-based modules demand a departure from routine teaching practices, requiring a comprehensive reorganisation of learning materials. They relied on existing SSI-based materials for guidance, signalling the necessity for supportive resources to aid teachers in crafting effective learning modules tailored to the SSI approach. Given the nature of SSI discussions where students share opinions, teachers are required to cultivate an environment where diverse voices can emerge in a safe space. This contrasts with the conventional teaching model, where discussions often culminate in definitive conclusions. If teachers embrace this disequilibrium, they could foster further student reflection and actions representing a departure from deeply ingrained pedagogical norms. Shifting from providing definitive answers to facilitating exploratory student learning demands continuous effort on the part of teachers and teacher educators alike.

The experiences of both Ruby and Surabhi highlight how the incorporation of SSIs into the pedagogical framework necessitates not only instructional adaptation but also a fundamental shift in the teacher's mindset and role within the classroom. To conclude, the dialogic approach and reflective practices emerged as effective strategies in orienting teachers towards the SSI-based paradigm and directing their attention towards various facets of SSI. The study employed an "Activity-modelling" approach, utilising effective teaching-learning tools like 'mind-mapping' and 'probing' to enable teachers to explore and analyse SSI-related aspects and the SSI-based approach itself, thereby nurturing the requisite PCK. Both teachers' learning modules encompassed three central components: analysing the issue from multiple dimensions (including scientific), identifying stakeholders and their perspectives, and dissecting dilemmas or challenges.

These components provided ample room for students' deliberations, perspective-building, and evidence-based thinking. Ultimately, the role of teachers in this learner-centric approach is paramount in determining the success of SSI-based discussions (Zeidler et al., 2005). The teachers' familiarity with their students' backgrounds and contexts, coupled with their proactive approach, paved the way for effective SSI-based instruction.

This study contributes to the science education literature by providing new insights into the integration of SSIs in science education by highlighting the importance of a structured framework to support teachers in developing SSI-based teaching and learning experiences. The study also highlights the need for ongoing support and resources for teachers to facilitate effective implementation of the SSI-based approach. It also adds to the literature by confirming the importance of teacher professional development and the need for ongoing support and resources to facilitate effective implementation of SSI-based teaching. The study also challenges the existing pedagogical practices where teachers and students are conditioned to have definite answers and highlights the need to encourage teachers to adopt a more facilitative and dialogic approach. Furthermore, the study also contributed to the importance of teachers' identity and beliefs in shaping their adoption of SSI-based approaches and how targeted teacher professional development programs can influence teachers' beliefs and practices.

The study provides a nuanced understanding of integrating SSI-based pedagogy in Indian classrooms, but it is crucial to acknowledge certain limitations while interpreting and generalising the findings. The small purposive sample of two teachers from two distinct schools with unique cultural and educational contexts limits the generalisability of the findings. The qualitative case study design, while offering rich insights, is susceptible to the researcher's bias and subjective interpretation, especially when the first author is involved in the module development process. Moreover, the COVID-19 pandemic added further contextual challenges that may have influenced the study's outcomes.

The implications of the study are significant for teacher education programs, curriculum development, and classroom practices. The study recommends that teacher education programs prioritise the SSI-based teaching in science education to promote a holistic science teaching and learning process. The study also urges the curriculum developers to consider integrating an SSI-based approach that is contextualised to local issues and aligned with sustainability goals into the science curriculum. At the classroom level, teachers are urged to adopt student-centred, discussion-based pedagogies that engage learners in deliberations about socioscientific issues and promote critical scientific literacy. Theoretically, the study contributes to the models of teacher change in resource-constrained settings by demonstrating how shifts in teachers' pedagogical orientations are tied to reflective practices. It also extends the curriculum integration discourse by showing how SSIs can become the core content rather than the mere 'add-on' when supported by contextualised professional development.

Future research should explore the long-term impact and sustainability of SSI-based pedagogy on student learning outcomes, particularly in scientific literacy, critical thinking, and decision-making. Further research can be done to investigate the role of teacher identity, beliefs, and self-efficacy in adopting SSI-based pedagogy to provide valuable perspectives on factors that enable or constrain its implementation. Furthermore, comparative research across diverse sociocultural contexts within India may provide insights into how cultural, economic, and institutional factors influence teachers' engagement with the SSI-based approach.

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