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Enhancing Indonesian Pre-service Science Teachers' Understanding of the Nature of Science, Technology, and SSI Teaching

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Abstract

This study examined the effects of the ENACT project, an intervention designed to enhance Indonesian pre-service science teachers' (PSTs) understanding and engagement with socioscientific issues (SSIs). Ninety PSTs majoring in physics, biology, and chemistry education participated in real-world problem solving and critically evaluated in societal, environmental, and ethical dimensions of science and technology. Data were collected through questionnaires, interviews, and artifacts produced during the project. Results showed significant improvement in PSTs' understanding of nature of science and technology (NOST) and SSI-based teaching. PSTs recognized the complex and often dualistic nature of technological advancements and valued their broader societal implications. They also reported stronger beliefs about the importance of integrating SSIs into science instruction and greater confidence in planning and implementing SSI-based lessons. The findings highlight the potential of structured interventions such as ENACT to prepare future teachers to address the multifaceted challenges of science and technology in society.

Keywords

SSI teaching – pre-service science teacher – ENACT program – nature of science and technology – perception of SSI teaching

1 Introduction

As contemporary societies face increasingly complex scientific, technological, and environmental challenges, the integration of socioscientific issues (SSIs) has gained significant attention in science education. SSIs are inherently complex, controversial, and ill-structured, requiring students to integrate scientific knowledge with moral and ethical considerations while evaluating economic and societal impacts (Sadler et al., 2016; Zeidler & Sadler, 2007). Meaningful engagement with SSIs enables students to confront pressing societal issues, explore ethical dilemmas, and reflect on the broader consequences of technological advancement, thereby fostering scientific literacy as citizens (Gul & Akcay, 2020; Ratcliffe & Grace, 2003; Sadler et al., 2007).

Despite the pedagogical value of SSIs, implementing SSI-based instruction remains a considerable challenge for science teachers. Teaching SSIs requires not only strong content knowledge but also pedagogical expertise in facilitating discussions, addressing ethical and social aspects, and cultivating students' critical reasoning (Lee, 2022). Moreover, institutional and structural barriers, such as rigid curricula, limited instructional resources, and time constraints, frequently hinder the integration of SSIs into classrooms (Markauskaite & Goodyear, 2014).

Another critical barrier for science teachers arises from their epistemological orientations toward the nature of science and technology (NOST; Day & Bryce, 2011; Witz & Lee, 2009; Zeidler et al., 2011). Many teachers, particularly in physics and chemistry, have formative experiences that lead them to deeply value the explanatory power of science, fostering a strong allegiance to its authority. As a result, such teachers are often less attuned to the contested and value-laden dimensions of science (Witz & Lee, 2009). However, the effective enactment of SSI-based instruction demands a fundamental restructuring of science teaching to embrace complexity, uncertainty, and sociocultural considerations (Zeidler et al., 2011). As Day and Bryce (2011) contended, this shift entails a paradigmatic reorientation in teachers' beliefs about science. Accordingly, supporting teachers in developing a more nuanced understanding of NOST is essential for enabling the meaningful and sustainable integration of SSIs into science teaching.

Indonesia faces numerous SSI-related challenges, including environmental degradation, deforestation, biodiversity loss, and social inequality resulting from rapid industrialization. Since SSI-based education has only recently been introduced, its efforts to prepare teachers for its implementation have remained relatively limited. Previous studies have indicated that Indonesian science teachers generally recognize the educational potential of SSIs, but many have hesitated to implement them due to limited pedagogical expertise, a lack of training opportunities, and insufficient teaching materials (Nida, Mustikasari, & Eilks, 2021; Nida, Rahaya, & Eilks, 2021). Additionally, centralized curricula, an exam-driven teaching culture, and restricted professional autonomy have posed further challenges to innovative science instruction (Subiantoro, Treagust, & Tang, 2021).

In this study, we suggest that the capacity of Indonesian pre-service teachers (PSTs) should be enhanced to effectively teach SSIs. One of the essential arguments for PST education has been the formative nature of this stage in shaping professional identity and pedagogical beliefs (Viehmann et al., 2024). During their university preparation, PSTs construct foundational understandings of science and pedagogy that strongly influence their subsequent teaching practices and often prove resistant to change once they enter the profession (Kılıç, 2022; Witz & Lee, 2009). For example, Van der Merwe (2022) found that pre-service teachers valued the knowledge and skills acquired during their programs as essential preparation for the teaching profession, while Jamil et al. (2024) demonstrated that they attached particular importance to the pedagogical approaches emphasized in their training. This indicates the necessity of incorporating SSI-based instruction at this formative stage to cultivate reflective and socially responsible science educators.

Therefore, we adopted a structured and guided training program consisting of five stages: engage, navigate, anticipate, conduct, and take action (ENACT). These stages are designed to foster PSTs' understanding of NOST and competencies in planning and delivering effective SSI-based instruction. The ENACT program is a project-based approach through which PSTs investigate an SSI of personal or local significance. The initial stages guide them in examining NOST related to their chosen issue, while the latter stages involve applying scientific or engineering methods to develop solutions, propose actions, and initiate implementation. The program thus seeks to enable PSTs to explore the scientific and technological underpinnings of SSIs, engage with real-world concerns, and critically reflect on how and why to teach SSIs as future educators.

We believe that the ENACT program holds significant potential for supporting Indonesian PSTs, especially those with limited exposure to SSI-based

education, by offering structured opportunities to engage with locally relevant issues and to participate in reflective problem-solving activities. Building on this premise, the research questions guiding it were constructed as follows:

1. To what extent does the ENACT program enhance PSTs' understanding of NOST?
2. To what extent does the ENACT program improve PSTs' understanding and pedagogical competence in SSI-based instruction?

2 Literature Review

2.1 *Challenges of SSI Integration in Indonesian Science Education*

In recent years, there has been a growing emphasis on SSI education in Indonesia. From the late 2010s to the early 2020s, several researchers have examined various aspects of SSI-based instruction, including the perceptions of in-service and pre-service science teachers (e.g., Nida, Rahayu, & Eilks, 2021; Nida, Mustikasari, & Eilks, 2021; Wiyarsi et al., 2024), efforts to enhance professional competencies (e.g., Subiantoro, Treagust, & Tang, 2021; Faisal & Martin, 2022), and the effectiveness of SSI-based lessons in classroom settings (e.g., Erna et al., 2023; Herlanti et al., 2012; Ismawati & Pertiwi, 2019; Pratiwi, Rahayu, & Fajaroh, 2016). However, Indonesia's national science curriculum remains predominantly content oriented (MOEC, 2016), posing challenges for the broad implementation of SSI-based instruction.

Although many science teachers have acknowledged the need for SSI integration, only a small proportion have reported implementing it regularly in their teaching. The most commonly cited barriers included students' limited reasoning skills, teachers' lack of professional expertise, curricular rigidity, inadequate teaching resources, and insufficient preparation time. Similar patterns have been observed among PSTs. Nida, Mustikasari, and Eilks (2021) found that Indonesian PSTs recognized the potential of SSI to promote scientific literacy, critical thinking, and ethical reasoning. However, they tended to express concerns about the interdisciplinary and controversial nature of SSI topics (Faisal et al., 2025). Given their limited teaching experience, PSTs often felt unprepared to lead classroom discussions on socially and ethically sensitive issues. In a related study, Nida, Pratiwi, and Eilks (2021) examined how Indonesian PSTs incorporated real-world contexts (e.g., SSIs) into their teaching during internships. They found that most of PSTs used them as introductory tools to enhance student motivation and engagement, rather than as central themes for deeper classroom inquiry or debate. This indicates that,

although PSTs acknowledge the relevance of SSI in science education, they may lack the pedagogical strategies and confidence required for its effective implementation.

2.2 *Efforts to Enhance Science Teachers' Understanding of and Competency in Teaching SSIs*

To facilitate the integration of SSIs into science instruction, various professional development initiatives and instructional resources have been designed to improve teachers' competence in SSI pedagogy. For instance, Ekborg et al. (2013) provided science teachers with instructional manuals and lesson design activities based on SSI case studies. The study reported increased confidence in SSI-based instruction and improved student engagement. However, a key finding was that many teachers still viewed SSI teaching as an isolated project rather than an integral component of their regular curriculum – highlighting a disconnect between SSI content and routine classroom practice.

Similarly, Subiantoro, Treagust, and Tang (2017) and Faisal and Martin (2022) developed professional development programs aimed at improving Indonesian science teachers' conceptual understanding and instructional strategies related to SSIs. These programs provided theoretical foundations and structured lesson-planning activities, which helped teachers develop more organized approaches to SSI-based instruction. Nevertheless, most of these initiatives focused primarily on in-service teachers, offering limited opportunities for pre-service teachers to engage directly in authentic SSI-based learning. Nida, Mustikasari, and Eilks (2021) noted that Indonesian PSTs generally have had minimal exposure to SSI-related activities, both during their secondary education and in university-based teacher preparation programs. Consequently, many PSTs reported feeling unprepared to discuss SSIs and lacked the confidence to implement SSI-focused lessons effectively.

To address this gap, the present study implemented the ENACT program, which offers Indonesian PSTs authentic, hands-on experiences in addressing SSI-related challenges. The ENACT model is a project-based approach consisting of five stages through which PSTs independently identify and investigate an SSI of personal or local relevance. The initial stages guide participants in exploring the nature of science and technology in connection with the selected issue. In the later stages, PSTs apply scientific or engineering practices to design solutions, propose actions, and take concrete steps toward implementation.

Previous studies have demonstrated the effectiveness of the ENACT program in promoting students' engagement with SSIs. For instance, Lee, Ko, and Hong (2022) implemented the program with Korean PSTs and reported that participants were able to critically reflect on the social roles and responsibilities of

scientists and engineers. Similarly, Choi et al. (2021) applied the ENACT program to pre-service technology teachers, who described the experience of investigating and addressing real-world or personally meaningful issues as particularly impactful. These teachers also reported that the program not only improved their scientific and technological knowledge but also deepened their understanding of the societal dimensions of science and technology.

3 Methods

3.1 *Participants*

This study employed a quasi-experimental design, utilizing a pre- and post-test structure to examine the impact of the intervention. Ninety PSTs participated in the ENACT program. All participants were enrolled in a mandatory three-credit course on science teaching methods, which covered the theoretical foundations and instructional strategies of science education. PSTs were assigned to separate sections according to their majors – biology education (BIO), physics education (PHY), and chemistry education (CHEM) – with each section consisting of 30 PSTs. The majority of PSTs were female ($n = 81$, 90%), and 65.5% ($n = 59$) indicated an intention to pursue a teaching career upon graduation.

3.2 *Intervention: the ENACT Program*

The ENACT program was implemented as one of the learning models within the course. The ENACT program adopts a structured, iterative approach consisting of five stages: engage (E), navigate (N), anticipate (A), conduct (C), and take action (T). As illustrated in Figure 1, the program is organized into two sequential cycles comprising these five stages.

Indonesian PSTs participated in the ENACT program over a 7-week period within a 15-week semester, with each weekly session lasting approximately 140 to 150 minutes. Each group consisted of five PSTs. Prior to engaging in the program, the PSTs received instruction on foundational learning theories and science teaching strategies and were introduced to the ENACT program (1st week). Upon completing the program, they shared their proposed solutions with others (7th week).

Cycle 1 focused on transforming PSTs' epistemological beliefs about science and technology (2nd–4th weeks). In Stage 1, PSTs were guided to select a SSI they wished to explore. They selected a wide range of SSIs for discussion. These included the dangers of silent electric motorcycles; accumulation of medical waste from COVID-19 vaccines and its risks to health and environmental

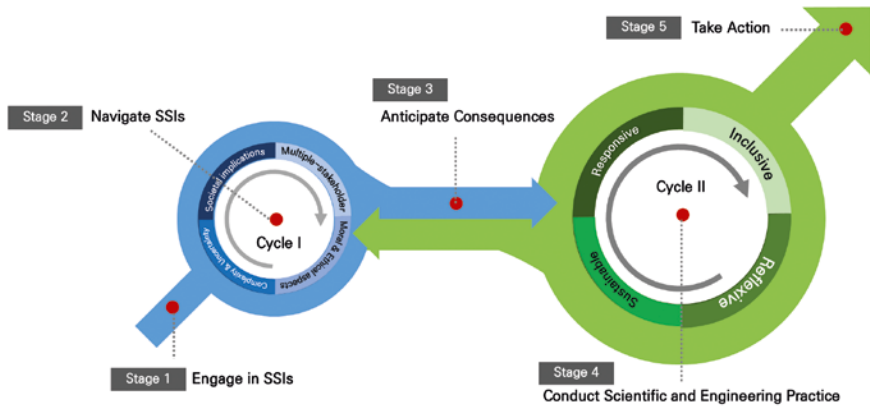


FIGURE 1 The ENACT project model (adapted from Lee et al., 2020, p. 10)

safety; soil pollution linked to artificial rain during dry seasons; river pollution caused by palm oil mill waste; declining biodiversity due to deforestation and illegal logging; problems related to abandoned cats; inadequate drainage systems leading to flooding and water intrusion; smoke from household waste burning near residential areas; and health risks associated with alcohol-based perfumes. In Stage 2, they investigated the selected issue and analyzed its various dimensions using stakeholder maps, including the social implications of science and technology, multiple stakeholder perspectives, ethical and moral considerations, and the inherent complexity and uncertainty of the issue. In Stage 3, they engaged in future-oriented thinking by brainstorming potential consequences of the issue. Using strategies in the future study fields (e.g., futures wheel and future scenarios), they envisioned both a concerning, probable future scenario and a desirable alternative, then generated ideas to bridge the gap between these two futures. Overall, in Cycle I, PSTs selected an SSI of their own interest and engaged in activities such as constructing stakeholder maps, developing futures wheels, and writing future scenarios. Through these processes, they were guided to understand NOST as being entangled with diverse societal groups and inherently characterized by uncertainty.

Cycle II involved a structured problem-solving process, during which PSTs applied scientific and engineering practices (5th and 6th weeks). In Stage 4, they were encouraged to incorporate the principles of responsible research and innovation, responsiveness, inclusivity, reflexivity, and sustainability (Stilgoe et al., 2013; Tassone et al., 2018), in order to promote socially responsible and sustainable outcomes. PSTs engaged in activities aimed at developing solutions for the SSI selected in Cycle I by employing diverse inquiry approaches (e.g., scientific experimentation, questionnaire surveys, and creative design),

while taking into account the responsible research and innovation principles. In Stage 5, they translated their ideas into concrete actions, such as participating in community service or outreach initiatives. For instance, one PST group implemented their plan by launching a community-focused awareness campaign. This included designing posters, producing informational materials, and engaging directly with local residents to raise awareness about the environmental and health risks of waste burning. They intended this process as a means of developing a deeper understanding of the role of science and technology in shaping society and cultivating a heightened sense of social responsibility.

3.3 Data Collection and Analysis

3.3.1 Instruments

As shown in Table 1, two validated questionnaires were adapted to assess the targeted constructs: the Student Concepts of the Nature of Technology Questionnaire (Liou, 2015) and the Questionnaire on Perceptions of sSI Teaching (Kwon & Lee, 2018). Both questionnaires employed a 5-point Likert scale format, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*), and demonstrated an acceptable level of reliability. They were reviewed by three experts in science education to evaluate their validity for the purposes of the present study and to assess whether each construct was appropriate in addressing the research questions. We administered the questionnaires before and after

TABLE 1 Reliability of the instruments

Instrument	Construct	No. of items	Cronbach's alpha
Student Concepts of the Nature of Technology Questionnaire	Technology as an innovative change (INNOVATIVE)	5	.702
	The current role of technology in society (ROLE)	5	.725
	Technology as a double-edged sword (2SIDE)	5	.717
Questionnaire on Perceptions of sSI Teaching	Interest in and understanding of sSIs (UNDERSTANDING)	5	.774
	Need and willingness to teach sSIs (NEED)	6	.703
	Efficacy in designing and implementing sSI-based lessons (EFFICACY)	7	.866

the implementation of the ENACT program. Questionnaire items are shown in Appendices A and B.

3.3.2 Student Concepts of the Nature of Technology Questionnaire (Liou, 2015)

Stages 1–3 of the ENACT program were designed to promote PSTs' understanding of NOST through the process of exploring SSIs. This understanding has been considered a foundational element for responsible SSI decision making and problem solving (Lee et al., 2020). To measure the change of PSTs' NOST through ENACT (Research Question 1), this study employed the Student Concepts of the Nature of Technology Questionnaire (SC-NOT) developed by Liou (2015). The instrument consists of 29 items across six factors.

Although the instrument was originally designed to assess high school students' view of the nature of technology, it was deemed appropriate for the purposes of this study for the following reasons. Most SSIs addressed in the literature encompass technological and engineering characteristics, such as biotechnology, environmental engineering, and energy engineering. In this sense, SSIs involve dimensions that cannot be regarded solely as matters of pure science (Lee & Lee, 2015, 2016). Furthermore, as evidenced in previous studies (Khishfe, 2012; Sadler, Chambers, & Zeidler, 2004), participants' discussions frequently referenced notions such as the dual nature of science and technology, the limitations of technology, and technology as a fix. In the context of SSIs, science is often situated closer to technology or engineering rather than being framed as "basic science." Thus, it was determined in this study that differentiating among science, technology, and engineering bore limited conceptual significance. An understanding of NOST in the study encompassed the capacity to recognize the features of science and technology within specific contexts and cases, such as SSIs, and to provide in-depth interpretation and analysis (Clough, 2013). In other words, this study sought to examine NOST from an integrative perspective. Thus, we felt that PSTs' understandings of NOST could be measured using the SC-NOT.

Among the six factors originally included in the instrument, we selected three factors that are closely aligned with the context of SSIs (15 items in total): Technology as an innovative change (INNOVATIVE), the current role of technology in society (ROLE), and technology as a double-edged sword (2SIDE). The first construct, INNOVATIVE, encompasses the dynamic and transformative role of technology in addressing human needs and advancing societal progress. It reflects the understanding that technology is not merely a collection of tools or artifacts, but a systematic application of scientific knowledge aimed at solving problems. It emphasizes technology's capacity to reshape human lifestyles, introduce novel solutions to persistent challenges, and serve

as a catalyst for continuous learning and adaptation. The second construct, *ROLE*, highlights the multifaceted contributions of technology to individual and societal advancement in the contemporary world. It underscores technology's pivotal role in promoting lifelong learning, expanding the frontiers of human knowledge, and enhancing personal competitiveness in an increasingly complex and dynamic environment. *2SIDE* captures the paradoxical nature of technological advancement, acknowledging both its profound benefits and its potential drawbacks. While technology enhances convenience and improves quality of life, it also poses risks when misused or over-relied upon. Thus, it emphasizes the need for critical reflection on the societal and ethical implications of technology, recognizing that its power to transform human life comes with inherent tensions and trade-offs.

3.3.3 Perception of SSI Teaching (Kwon & Lee, 2018)

We felt that participation in the ENACT program as PSTs may be effective in fostering an awareness of the importance of teaching SSI and enhancing their willingness to incorporate SSI into future classroom instruction. Since ENACT program consists of five structured stages, each accompanied by specific teaching strategies, we also anticipated an increase PSTs' confidence in planning and implementing SSI lessons, even among those with limited prior experience. Therefore, to investigate changes in Indonesian PSTs' perceptions of SSI-based instruction, this study employed the Perception of SSI Teaching instrument (Kwon & Lee, 2018). The instrument comprises 18 items across three factors: interest in and understanding of SSIs and teaching SSIs (*UNDERSTANDING*), need and willingness to teach SSIs (*NEED*), and efficacy in designing and implementing SSI lessons (*EFFICACY*).

The first construct, *UNDERSTANDING*, reflects an individual's cognitive and affective engagement with SSIs. It encompasses a personal interest in SSIs, the ability to engage in discourse about such issues, and a conceptual understanding of their complex, interdisciplinary nature. It also includes an appreciation of the educational significance of SSIs. The second construct, *NEED*, embodies the belief that science instruction should extend beyond factual knowledge to include the exploration of ethical, social, and value-laden dimensions inherent in real-world scientific issues. It emphasizes that science classrooms are uniquely positioned to engage students in critical discussions about the limitations and societal implications of science. Moreover, it indicates a proactive stance toward integrating SSIs into teaching practice, affirming the role of science teachers in fostering students' reflective and responsible engagement with science in society. The last construct, *EFFICACY*, pertains to science teachers' perceived competence in planning and delivering effective SSI-based instruction. It encompasses the ability to select relevant and meaningful SSI topics,

locate and organize appropriate instructional resources, and design coherent lesson structures. It also involves the strategic use of diverse pedagogical approaches such as discussions and debates to facilitate student engagement and critical thinking. It also includes the capacity to anticipate potential student difficulties, reflecting a thoughtful and adaptive approach to SSI teaching.

3.4 *Interviews with Individual PSTs*

Another data source was individual interviews with 32 PSTs after the ENACT program. Following the completion of the ENACT program, 32 PSTs voluntarily agreed to participate in interviews regarding their experiences with the program. Twelve PSTs from the physics education program, and 10 each from the biology and chemistry education programs, took part in the interviews. All participants demonstrated a high level of commitment throughout the 7-week ENACT program, with no more than one absence, indicating excellent attendance.

A semi-structured interview approach was selected to maintain focus on predefined issues related to the research questions while allowing for additional follow-up questions based on the interviewees' responses (Bryman, 2012). The interview questions were designed to complement the quantitative data and obtain detailed insights into the PSTs' perceptions and experiences of the ENACT program. The interviews were conducted 2–3 weeks after the completion of all course sessions. Each interview lasted 30–40 minutes. Additionally, PSTs' artifacts were collected to observe how they progressed in their projects. These artifacts included stakeholder maps, futures wheels or future scenarios, final reports, and presentations. Prior to the interviews, the researcher reviewed these materials to gain insight into each PST's engagement in the ENACT program and used this information to inform the development of interview questions. Examples of interview questions are as follows.

- Could you describe any changes in your thoughts about science and technology after participating in the ENACT program?
- During the program, you created stakeholder maps or futures wheels for the selected SSI. What new insights did you gain from this activity?
- As a future teacher, would you like to teach SSI? Why or why not?
- What challenges did you face while working on the ENACT project?

3.5 *Data Analysis*

Data from the questionnaires were analyzed to examine the changes of PSTs' perceptions of NOST and perceptions of SSIs and SSI teaching. Mean comparisons and descriptive statistical analyses were performed on the collected responses. To examine the impact of the ENACT program, a paired-sample

t-test was conducted on the pre- and post-test scores, and the effect size was calculated using Cohen's *d*. All statistics were tested at the .05 level of significance, and the results were analyzed using the SPSS statistical program.

All interview data were transcribed. All interviews with the PSTs were conducted in Indonesian (Bahasa Indonesia), the first author's native language. The first author, who is also proficient in English, translated the transcripts, and the second author reviewed the translations. Any ambiguous expressions were discussed until agreement was reached, ensuring the English versions reflected the original meaning as accurately as possible.

Prior to coding, the researchers carefully reviewed the transcripts multiple times to gain an in-depth understanding of the content (Creswell, 2007). This study aimed to explore changes in PSTs' perceptions across two key areas: their understanding of NOST and perceptions of SSI-based instruction. We especially focused on identifying whether and how shifts in these factors of the areas occurred. This analysis followed the key stages of coding outlined by Miles, Huberman, and Saldana (2013). In the initial round of coding, we read through the transcripts and assigned codes to meaningful statements or passages. For example, the analysis sought to examine whether PSTs' perspectives on each factor of NOST changed through their engagement with the ENACT program, what specific aspects of their view evolved, and which components of the ENACT activities may have contributed to such changes. Regarding the PSTs' perceptions of SSI teaching, particular attention was given to understanding why their interest and understanding evolved as a result of participation in the ENACT program and to identifying the specific activities or experiences within the program that influenced their perspectives on SSI-based instruction. Finally, representative statements were selected for each domain of the ENACT program's intended effects. These statements were chosen both to illustrate the range of PSTs' perspectives and to provide pedagogical insights and are presented alongside the quantitative findings in the Results section. Interview excerpts are labeled with identifiers (e.g., *PST_PHY2*), denoting a response from a preservice teacher in the second group of participants majoring in physics. Similar coding conventions were used for other subject majors and groups.

4 Results

4.1 *Effect of the ENACT Program on PSTs' View on NOST*

The ENACT program emphasizes resolving SSIs on the basis of a deeper understanding of NOST. Therefore, we hypothesized that PSTs' views on NOST would

be enhanced by their participation in the ENACT program. To confirm the effect, the pre- and post-mean scores for the three factors were compared as shown in Table 2.

Table 2 presents the significant impact of the ENACT program on PSTs' perceptions of NOST. All factors demonstrated statistically significant increases in mean scores from pre-test to post-test. Among the three constructs, 2SIDE demonstrated the highest post-test mean, suggesting that PSTs developed a more nuanced understanding of the complex and dualistic nature of technological advancements. However, it demonstrated a relatively small effect size ($d = 0.22$). By contrast, the most substantial gain was observed in the ROLE factor, which showed the largest effect size ($d = 0.44$). This indicated a significant enhancement in PSTs' appreciation of the broader societal implications and contributions of science technology to daily life and global development.

The interviews with PSTs provided further support for the emergence of these changes. Many PSTs described a shift from viewing science as abstract knowledge to seeing it as deeply interconnected with societal and environmental issues, for instance, "Science isn't just about learning theories, it's also about how those ideas affect our world" (PST_BIO3) and "As someone who's going to teach physics, I used to think it was just about formulas. But after this program, I see that SSI brings those concepts to life" (PST_PHY2). This indicates that PSTs recognized the innovative potential of science and technology. They acknowledged science and technology as a means of addressing human challenges and, in doing so, bringing about transformations in human life.

They also articulated their perspectives on the pervasive integration of technology into their daily lives. They emphasized that technology exerts a

TABLE 2 Effect of ENACT program on PSTs' NOST

Factor	Pre		Post		<i>t</i>	<i>P</i>	<i>d</i>
	Mean	SD	Mean	SD			
Technology as an innovative change (INNOVATIVE)	3.79	0.51	4.20	0.49	7.54	.000	0.38
The current role of technology in society (ROLE)	3.74	0.58	4.18	0.41	8.43	.000	0.44
Technology as a double-edged sword (2SIDE)	3.97	0.53	4.29	0.45	5.04	.000	0.22
Total	3.83	0.40	4.22	0.37	10.71	.000	0.56

substantial influence on their social interactions and on their conceptualizations of the world, noting that technology supports the exploration of new areas of knowledge and inquiry. By enabling global access to information, the participants felt that technology broadens their horizons and enhances their capacity to engage with diverse perspectives, facilitating communication and collaboration, thereby enabling interaction with emerging innovations and learning from these experiences in meaningful ways. The following excerpts from interviews illustrate how PSTs articulated changes in their own perceptions of science and technology.

Reflecting on the topics we've explored, I've experienced a meaningful shift in how I understand science and technology. Initially, I thought of science as purely theoretical and technology as just complex systems. However, I've come to realize that both have clear, real-world impacts on our daily lives. This change in perspective has helped me better appreciate the practical value of scientific and technological developments, as well as their broader implications in society. (PST_CHEM1)

I believe technology holds great potential to improve human life in the future. However, it's important that we use it wisely and take into account all aspects of people's lives. Technology isn't just about being advanced or practical, it's also about how it can contribute positively to the overall well-being of society. (PST_BIO1)

The reflection provided by PST_CHEM1 underscores her recognition of the direct influence of science and technology on everyday life. This heightened awareness signifies an expanding understanding of their relevance in shaping societal development. In a similar vein, PST_BIO1 emphasized the necessity of employing technology judiciously, acknowledging its dual function as both a means of enhancing quality of life and a potential source of societal risk. PSTs perceived the ENACT program as having transformed their understanding of NOST, for example, "The ENACT program really helped me get a deeper sense of the challenges and possible consequences that come with the development of science and technology" (PST_BIO2). Other PSTs mentioned how the ENACT program changed their view of NOST:

Before joining the ENACT program, I honestly thought technology just meant advanced gadgets or electronic devices. But after taking part in the program, especially the discussions in Step 1 and Step 2, my perspective really changed. I realized that technology isn't only about modern

gadgets or digital tools. It's basically any kind of innovation or change that helps people and improves quality of life. With this broader view, I've come to appreciate how technology matters not just in high-tech settings but also in everyday solutions that really contribute to society's well-being and sustainability. (PST1_PHY3)

Joining Step 1 to Step 3 of the ENACT program really changed the way I see technology in society. By looking into local issues and thinking about different stakeholders' perspectives, I realized that technology is shaped by human choices and can have unintended effects on different groups. I also had to think about who benefits and who gets left out. ... I've realized how important technology is in tackling the sustainability challenges we're facing today. It really made me believe even more that using science and technology in a responsible and informed way is key to building a fairer and more resilient future. (PST_BIO3)

They particularly indicated that Steps 1, 2, and 3 of the program played a pivotal role in reshaping their perspectives on science and technology, a pattern similarly reported by other PSTs. The process of identifying SSIs in everyday life, exploring diverse stakeholder perspectives, and envisioning the potential impacts of technology on future society helped them recognize that science and technology are not merely tools, but rather innovative means capable of driving societal change. Moreover, these reflections highlighted their growing awareness that such impacts can vary by context, producing both positive and negative consequences. This outcome aligned well with the intended objectives of the ENACT program.

4.2 *Effects of the ENACT Program on PSTs' Perception of SSI Teaching*

The ENACT program offered PSTs a structured opportunity to explore and address SSIs, while simultaneously fostering reflective practices on the pedagogical importance of SSI integration in science education. Consequently, we anticipated that the program would not only deepen their comprehension of SSIs and methods of SSI-based instruction but also cultivate a strong motivation to integrate SSIs into their future teaching. Table 3 shows that their engagement with the ENACT program yielded statistically significant improvements across all three factors.

Among the three constructs, NEED exhibited the largest effect size ($d = 0.50$), followed closely by UNDERSTANDING ($d = 0.48$). This suggests that PSTs not only deepened their conceptual understanding of SSIs but also developed a stronger belief in the necessity of integrating SSIs into science instruction.

TABLE 3 Effect of ENACT program on PSTs' perception of SSI teaching

Factor	Pre		Post		<i>t</i>	<i>p</i>	<i>d</i>
	Mean	SD	Mean	SD			
Interest and understanding of SSI (UNDERSTANDING)	3.24	0.51	3.76	0.51	9.10	.000	0.48
Need and willingness to teach SSI (NEED)	3.41	0.50	3.94	0.40	9.52	.000	0.50
Efficacy in designing and implementing SSI lessons (EFFICACY)	3.55	0.52	3.92	0.47	6.46	.000	0.31
Total	3.42	0.39	3.88	0.37	12.33	.000	0.63

Although EFFICACY showed a relatively smaller effect size ($d = 0.31$), modest but meaningful gains were found in PSTs' confidence in planning and implementing SSI-based lessons.

Interview data supported the quantitative findings, revealing how the ENACT program reshaped PSTs' interests and understanding of and attitudes toward SSI teaching. PSTs noted that SSI approaches can not only deepen content understanding but also foster active classroom participation, student motivation, and richer teacher-student interactions.

One thing I really noticed is how SSI make the class feel more alive. Students [PSTs in class] weren't just sitting there. They were actually talking, sharing, and thinking bigger. And because the issues were real, they cared more. It made the lessons feel way more meaningful. (PST_CHEM4)

Doing SSI projects in class helped us connect science to stuff they actually experience. They [PSTs in class] started asking better questions and really worked together. It didn't feel like school in the usual way. It felt like we were doing something that mattered. (PST_CHEM2)

As shown in the excerpts, most of the PSTs demonstrated strong engagement with topics that link science to real-life issues, reflecting genuine curiosity and enthusiasm for exploring the societal implications of science and technology. This interest indicated that PSTs not only recognized the importance of incorporating SSIs into their teaching but were also motivated to engage with and

develop a deeper understanding of these topics. Such enthusiasm is essential for effective SSI-based instruction, as it encourages PSTs to design more relevant and impactful learning experiences for their students, thereby bridging the gap between scientific knowledge and its societal applications.

The responses of PSTs, including the following excerpts of PST_CHEM3 and PST1_BIO4, indicate that their experiences in the ENACT program provided them with opportunities to critically reflect on the future direction of science instruction.

I think using SSIs is really the direction science classes need to go. The world is complicated, and students need to see how science connects with society and tech. It's not just about learning stuff. It's about using it to think through real problems. That's what I want to teach. (PST_CHEM3)

At first, I thought SSI were just about science, but now I see they're really about everything, how science fits into people's lives. The best part was when we looked at problems from our community. That's when students really got into it. They weren't just learning, they were trying to fix things. (PST1_BIO4)

They strongly agreed that science education should move beyond the mere transmission of concepts and knowledge toward enabling students to explore the complex problems of the real world through SSIs, thereby connecting science with everyday life. Most PSTs emphasized that one of the key strengths of the ENACT program was its incorporation of community-based issues into science lessons. They recognized that such issues not only foster student engagement but also position learners as active participants in the process of authentic problem solving. Consistent with the improvements observed in the NEED factor reported in Table 3, many PSTs expressed their intention to implement SSI-based instruction in their future classrooms.

As shown in Table 3, the intervention notably enhanced PSTs' sense of efficacy in designing and implementing SSI teaching (EFFICACY).

I feel way more confident now about designing physics lessons that include SSIs. Like, I can totally imagine making a unit on energy conservation that doesn't just stop at the laws of thermodynamics, but also looks at the ethical, environmental, and social sides of renewable energy. This experience really showed me how to help students dig into complicated issues, think from different perspectives, and come up with evidence-based solutions, which I think are super important not just

for science but for being an active citizen. I feel ready to try this out in my future classes and help students see how physics connects to the real world. (PST_PHY6)

Like PST_PHY6, most PSTs reported that participation in the ENACT program to some extent made them feel more confident and capable of planning and carrying out SSI-based instruction. The ENACT program employs a variety of instructional strategies at each stage to enable participants to select and address SSIs. For instance, PSTs engage in constructing stakeholder maps to examine diverse perspectives related to SSIs and apply their scientific and engineering knowledge to explore possible solutions. This process not only helped PSTs recognize the connections between SSIs and science subject matter but also deepened their understanding of multiple strategies for teaching SSIs. However, the interview data revealed that they also acknowledged persistent concerns regarding potential challenges in implementing such lessons.

I'll be honest, it wasn't easy at first. Figuring out what issues to use or how to guide the discussion was kind of tricky. But once I got into it, I saw how powerful it could be. It really pushes students to think beyond just the right answer. (PST2_PHY3)

SSIs are a great idea, but we need better resources if it's really going to work. Not every school has the time or materials for this kind of teaching. I get it now, but we'll need support to do it well. (PST2_BIO4)

This candid account from PST_PHY3 reflected the learning curve many novice teachers face when implementing new pedagogical approaches. Yet his experience also underscored the transformative potential of sustained SSI engagement. PST_BIO4 articulated a key structural barrier to SSI adoption. Her recognition of the need for institutional and material support aligned with broader calls in the literature for systemic changes to enable innovative science instruction.

These responses revealed that the ENACT program helped PSTs reconceptualize the goals and possibilities of science education. Through SSIs, they came to see science as not only a body of knowledge but also a means for social relevance, ethical reflection, and democratic participation. While challenges remain, particularly in implementation, PSTs expressed a strong desire to incorporate SSI into their future classrooms. Their reflections affirmed the value of SSI-based instruction in developing scientifically literate citizens prepared to engage with the complex, value-laden issues of the modern world.

5 Discussions and Implications

This study was initiated in response to the growing need for science teacher education that meaningfully connects science instruction to real-life contexts through SSIs, particularly in light of the complex SSIs emerging in Indonesia. To address this need, the ENACT program was implemented as an educational intervention designed to provide Indonesian PSTs with opportunities to experience dealing with SSIs and considering the nature of science and technology embedded in SSIs. As a result, the program yielded several positive outcomes, as discussed below.

First, the findings indicated a significant improvement in PSTs' understanding of NOST. Whereas science and technology had initially been regarded as neutral and objective products, they increasingly came to be recognized as socially constructed entities embedded with ethical dimensions that bear significant implications for both human life and the environment. This conceptual shift signified a deeper development of PSTs' reflective thinking concerning the societal role of science and technology. This finding was consistent with Waight's (2014) observation that teachers frequently perceived technology as a benevolent force and a symbol of societal advancement. However, the present study indicated a more substantive conceptual shift. PSTs increasingly recognized that technological progress must be accompanied by ethical deliberation. From a pedagogical perspective, this emergent awareness supports the development of science instruction that transcends the transmission of factual knowledge, instead fostering critical engagement with the interrelationships among science, technology, and society. Such an approach aligns with the perspectives of Boerwinkel et al. (2014) and Hodson (2020), who underscored the importance of integrating ethical and societal considerations into science education as a means of cultivating students' moral sensitivity and civic responsibility.

Second, with regard to readiness for implementing SSI-based instruction, PSTs exhibited increased enthusiasm and confidence after the ENACT program. They reported feeling better equipped to design lessons that are contextualized, collaborative, and centered on real-world SSIs. This shift holds particular significance in the Indonesian context, where science education has traditionally emphasized rote memorization and high-stakes examinations. Although the current Indonesian curriculum emphasizes contextual and values based learning through the *Profil Pelajar Pancasila* (Pancasila Student Profile; Ministry of Education, Culture, Research, and Technology, 2024), its implementation in schools has not been consistent. The framework is based on *Pancasila*, the Indonesian state philosophy made up of five principles of

belief in God, humanity, national unity, democracy, and social justice, and it describes six learner attributes of faith, global citizenship, collaboration, critical reasoning, creativity, and independence. The effective integration of SSIs into school curricula depends not only on the preparedness of individual teachers but also on broader systemic conditions, including curricular flexibility, supportive policies, and institutional capacity.

While the ENACT program contributed to an enhancement of PSTs' perceptions of SSI teaching, this improvement might appear to be partial and tentative. As highlighted in prior research (Nida, Mustikasari, & Eilks, 2021; Subiantoro et al., 2021), PSTs often continue to struggle when confronted with the practical demands of addressing SSIs in classroom settings. The findings of this study echo this concern, as several PSTs anticipated persistent challenges in introducing SSIs, thereby underscoring the gap between conceptual recognition and pedagogical enactment. This suggests that sustained support, scaffolded practice opportunities, and institutional reinforcement are essential if the initial shifts in perception are to be translated into consistent and effective classroom practice.

We believe that the application of the ENACT program in the Indonesian teacher education context presents several meaningful implications for improving PST training. First, as shown in the PSTs' responses, the program encouraged the integration of locally relevant and contextualized issues into science instruction. By selecting authentic problems from their surroundings, such as waste management, deforestation, or water pollution, PSTs believed that they could make science learning more meaningful for their students (Kim, Ko, & Lee, 2020; Powers, 2004). This contextualization is especially important in Indonesia, where socioenvironmental challenges vary significantly across regions.

In addition, the ENACT program fosters civic engagement by linking science learning with social responsibility (Lee, Ko, & Hong, 2022). Through Steps 4 and 5, which involve proposing solutions, conducting investigations, and taking action, PSTs are not merely learning content but are empowered to become curriculum designers and facilitators of social change. The emphasis on action-oriented projects (e.g., campaigns or community outreach) resonates well with Indonesia's educational values based on the broader goal of character education. Pre-service teachers trained with the ENACT program are more likely to encourage student participation in real-world decision making and foster a sense of agency among their future students. Furthermore, incorporating scientific and engineering practices (Step 4) addresses a major gap in current science education practices in Indonesia, where practical and inquiry-based experiences are limited. By learning to identify problems and

implement solutions, future teachers can better support students in engaging with complex, interdisciplinary problems in a hands-on way, in line with the goals of science and STEM education reforms.

Abbreviations

SSI	Socioscientific issue
PST	Pre-service science teachers
ENACT	Engage, navigate, anticipate, conduct, and take action
INNOVATIVE	Technology as an innovative change
ROLE	The current role of technology in society
2SIDE	Technology as a double-edged sword
UNDERSTANDING	Interest in and understanding of SSI
NEED	Need and willingness to teach SSI
EFFICACY	Efficacy in designing and implementing SSI lessons

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Ethical Consideration

Approval to conduct this study was granted by the Ewha Womans University Institutional Review Board (IRB). The necessary clearance from the participants involved in the study was obtained for the data collected in this paper.

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Appendix A

PSTs' perception of NOST

Items	Pre-test		Post-test	
	Mean	SD	Mean	SD
1. Technology can assist in accomplishing the tasks that humans cannot achieve.	3.90	.912	4.32	.716
2. Technology can change human lifestyles by applying science knowledge.	3.74	.646	4.24	.587
3. Technology is the products developed in the process of solving humans' problems.	3.72	.704	4.12	.615
4. Technology indicates a new method to solve the problems in human life.	3.67	.764	4.09	.744
5. Technology is a process involving continuous learning and transformation.	3.90	.720	4.22	.700
INNOVATIVE Total	3.78	.509	4.20	.491
6. Technology can stimulate humans' perpetual learning.	3.30	.930	3.88	.684
7. Technology can assist humans in exploring unknown phenomena	3.90	.794	4.23	.654
8. The application of technology can enhance individual competitiveness.	3.63	.771	4.16	.634
9. Technology is beneficial to society and the world.	4.03	.827	4.33	.670
10. Technology is the driving force that leads to the progress of human beings.	3.82	.856	4.32	.684
ROLE Total	3.73	.577	4.18	.413
11. Technology has been a part of our daily life, but people tend to abuse it.	4.11	.800	4.36	.724
12. Technology can improve our life, but its use may also lead to negative effects.	4.18	.696	4.50	.566
13. Over-reliance on technological products leads to an increase in social alienation.	4.08	.707	4.22	.761

PSTs' perception of NOST (*cont.*)

Items	Pre-test		Post-test	
	Mean	SD	Mean	SD
14. The crimes committed in recent years have changed along with Scientific and technological breakthrough.	3.69	.870	4.13	.706
15. Technology makes human life much more convenient but leads to a regression in the basic activities of daily living.	3.81	.820	4.26	.712
2SIDE Total	3.97	.534	4.29	.449

Appendix B

PSTs' perception of SSI teaching

Items	Pre-test		Post-test	
	Mean	SD	Mean	SD
1. I am usually interested in socioscientific issues (SSIs).	3.50	.738	3.83	.753
2. I am able to talk to my friends (or others) about SSIs that interest me.	3.67	.670	3.87	.722
3. I understand the nature of SSIs.	2.91	.664	3.67	.703
4. I understand what it means to be educated about SSIs.	3.07	.716	3.82	.628
5. I can estimate educational impact of SSI-based instruction.	3.07	.716	3.62	.628
UNDERSTANDING Total	3.24	.508	3.76	.509
6. I think SSIs should be introduced in science classes.	3.31	.788	4.13	.622

PSTs' perception of SSI teaching (*cont.*)

Items	Pre-test		Post-test	
	Mean	SD	Mean	SD
7. I think science courses are better suited to introduce SSIs than social studies or ethics courses.	3.14	.894	3.70	.694
8. I think students should recognize that science has social and ethical dimensions.	3.76	.676	4.03	.550
9. I believe that students should be taught that science may not always provide the right answers on SSIs.	3.18	.869	3.78	.884
10. I believe that science teachers should address SSIs in the classroom where science has embedded values.	3.57	.780	3.97	.644
11. If I were a science teacher, I would incorporate SSIs in my classroom.	3.51	.738	4.02	.580
NEED Total	3.41	.503	3.93	.400
12. I am able to plan SSI lessons.	3.47	.657	3.78	.595
13. I can select appropriate topics for SSI lessons.	3.48	.640	3.97	.626
14. I can find resources for SSI lessons.	3.39	.682	3.86	.628
15. I can organize materials for SSI lessons.	3.34	.690	3.81	.685
16. I can identify different teaching methods (e.g., discussions, debates, etc.) for SSI class.	3.76	.692	4.04	.598
17. I can utilize a variety of teaching methods (e.g., discussions, debates, etc.) for SSI class.	3.86	.728	4.14	.646
18. I can anticipate the challenges students may face in SSI lessons.	3.60	.761	3.87	.657
EFFICACY Total	3.55	.516	3.92	.466