From Classroom To Community: Evaluating A Socio-Scientific Literacy Intervention On Plastic Pollution For Sustainable Development In Schools

Megha Suvagiya, Prof. Divya Sharma

Research Scholar, Prof. & Guide,

Indian Institute of Teacher Education, Gandhinagar, Gujarat

Abstract: The present study examined the effectiveness of a Socio-Scientific Issue (SSI)-based literacy programme in enhancing students' environmental awareness, attitudes, and willingness to engage in sustainable actions, with a particular focus on plastic pollution. A quasi-experimental design was employed with two groups: an experimental group (n = 28) exposed to the SSI-based programme and a control group (n = 27) taught through traditional instruction. Data were collected using the CHEAKS scale (Children's Environmental Attitude and Knowledge Scale) through pre- and post-tests. The results revealed significant within-group gains for the experimental group, $t(27) = 4.32$, $p < .001$, Cohen's $d = 1.28$, while the control group showed no significant improvement, $t(26) = 0.96$, $p > .05$. Between-group analysis further confirmed a highly significant difference in gain scores, $t(53) = 11.86$, $p < .001$, with a very large effect size ($d = 3.20$), indicating the strong impact of the intervention. These findings highlight that SSI-based pedagogy substantially enhances students' understanding and commitment to addressing environmental issues compared to traditional methods. The study highlights the pedagogical potential of integrating real-world socio-scientific concerns into classroom teaching for promoting sustainable values and aligns with the vision of the National Education Policy (NEP) 2020 in fostering critical, responsible, and environmentally conscious learners.

Keywords: Environmental education, sustainability, NEP 2020, SSI-based pedagogy, plastic pollution, CHEAKS.

Introduction

Socio-scientific issues (SSIs) are complex, real-world problems such as climate change, genetic modification, and plastic pollution that intertwine scientific, ethical, political, and economic dimensions. Contemporary science education emphasizes SSI-based learning because it not only promotes scientific literacy but also nurtures moral reasoning, empathy, and civic engagement (Zeidler et al., 2005). Unlike traditional rote learning, this approach connects classroom knowledge to societal challenges, preparing students to act as informed and responsible citizens.

SSI pedagogies are particularly effective in bridging scientific content with community issues. Sadler (2011) notes that such instruction encourages learners to critically evaluate evidence, understand the complexity of public debates, and make reasoned, ethical decisions. These goals align with Education for Sustainable Development (ESD), which aims to empower individuals to address sustainability, equity, and global responsibility (UNESCO, 2017). Plastic pollution, a pervasive SSI that echoes with students' everyday lives, highlights the urgency of using an approach in science education which addresses such issues of the society. While plastic's durability once revolutionized modern life, its ecological consequences—biodiversity loss, food-chain contamination, and environmental imbalance—are now catastrophic. Research shows that SSI-based interventions can strengthen environmental awareness and foster pro-environmental behaviors among students (Kahn & Zeidler, 2017).

The present study investigates the impact of an SSI-based literacy program on 9th-grade students' awareness, attitudes, and willingness to engage in sustainable actions regarding plastic pollution. By integrating classroom dialogue with community-oriented activities, the intervention seeks to foster both scientific and civic literacy. The study is grounded in the belief that cultivating such competencies in young learners can contribute meaningfully to long-term sustainability and the achievement of the United Nations Sustainable Development Goals (SDGs).

Literature Review

The integration of Socio-Scientific Issues (SSIs) into science education has emerged as a powerful pedagogical approach to connect scientific knowledge with pressing societal concerns. Zeidler and Nichols (2009) argue that SSI-based teaching encourages learners to critically evaluate moral, ethical, and scientific dimensions of real-world challenges such as climate change, genetic engineering, and environmental degradation. Their work established a foundation for using SSIs not merely to enhance cognitive understanding but also to foster reflective and socially responsible behavior. Complementing this, Sadler (2004) demonstrated that engaging students in informal reasoning about socio-scientific dilemmas promotes argumentation skills, moral consciousness, and deeper scientific literacy. Building on these insights, Zeidler et al. (2005) proposed a comprehensive framework for integrating SSIs into classrooms to advance both scientific literacy and civic responsibility.

Several validated instruments have facilitated research in this domain. Leeming, Dwyer, and Bracken (1995) developed the widely used Children's Environmental Attitudes and Knowledge Scale (CHEAKS), which measures environmental awareness, concern, and behaviors among students. Similarly, Olsson, Gericke, and Chang Rundgren (2016) introduced the Sustainability Consciousness Questionnaire, highlighting the link between sustainability education and students' awareness, motivation, and behavioral intentions. Such tools have proven essential in assessing the outcomes of SSI-based and environmental education interventions.

Global education frameworks also support SSI pedagogies. UNESCO's (2017) report on Education for Sustainable Development (ESD) emphasizes competencies such as critical thinking, systemic understanding, and participatory decision-making, urging a shift from classroom-centered to community-centered learning. This aligns closely with SSI-based teaching, both aiming to prepare learners for ethical decision-making and proactive environmental stewardship. In this context, plastic pollution represents a particularly relevant SSI, as it directly connects students' daily experiences with broader sustainability concerns. Kurniawan et al. (2021), for example, identified school-based interventions as a key strategy for long-term behavioral change in addressing plastic waste across Southeast Asia. Similarly, Evagorou et al. (2014) found that classroom discussions on environmental SSIs foster empathy, global citizenship, and emotional engagement alongside cognitive development.

In India, emerging research highlights both potential and challenges in implementing SSI-based approaches. Sharma and Sharma (2020) found that project-based environmental education programs in Delhi schools improved students' ecological sensitivity and encouraged community engagement through activities such as plastic collection drives. Subramanian and Ramanathan (2018) reported a persistent gap between environmental knowledge and behavior among adolescents, arguing that SSI-based pedagogies can help make science learning personally relevant and actionable. However, structural barriers—such as rigid curricula, exam-driven instruction, limited teacher training, and the socio-political sensitivity of certain issues—continue to restrict SSI integration in classrooms (Lee & Witz, 2009).

Overall, the review of literature reveals that SSI-based pedagogies hold strong potential to transform science education by bridging knowledge with ethical reasoning, empathy, and civic responsibility. Yet, their widespread adoption depends on overcoming systemic barriers and equipping teachers with the necessary training and resources.

Research Gap and Rationale

Although SSI-based science education has gained increasing attention worldwide and aligns with frameworks such as the Sustainable Development Goals (SDGs) and India's National Education Policy (NEP) 2020, significant gaps remain in its contextual application within Indian school education. Much of the existing literature is grounded in theoretical models or focused on interventions in higher education and Western contexts, leaving limited empirical evidence on how SSI-based approaches function in Indian classrooms. Specifically, research exploring the cognitive, affective, and behavioral impacts of SSI-based programs on young adolescents in India is scarce.

Moreover, while validated tools such as the Children's Environmental Attitudes and Knowledge Scale (CHEAKS) and the Sustainability Consciousness Questionnaire have been widely used, their application to assess school-level SSI interventions addressing plastic waste is minimal. There is also a notable lack of studies examining the translation of classroom learning into community-oriented environmental action—an essential dimension of Education for Sustainable Development (ESD). In particular, urban Indian contexts, where plastic consumption and waste management challenges are most acute, remain underexplored in SSI-based research.

This study seeks to address these gaps by designing and implementing an SSI-based literacy program for Grade 9 students on the issue of plastic pollution. It evaluates the program's effectiveness in enhancing students' environmental awareness, attitude and willingness to engage in sustainable actions. By linking classroom-based SSI learning with community-oriented outcomes, the study positions SSI pedagogy as a practical and scalable approach to integrating sustainability with school curriculum in India.

Objectives

1. To design and implement a Socio-Scientific Issue (SSI)-based literacy programme focused on plastic pollution to foster sustainable development-oriented actions among students.
2. To examine the effectiveness of the SSI-based literacy programme in improving students' environmental awareness, attitudes, and willingness as measured through gain scores on the Children's Environmental Attitude and Knowledge Scale (CHEAKS).
3. To assess the influence of the SSI-based literacy programme on students' awareness of plastic pollution.
4. To assess the influence of the SSI-based literacy programme on students' attitudes toward sustainability and environmental responsibility.
5. To assess the influence of the SSI-based literacy programme on students' willingness to participate in sustainable community-based actions.

Hypotheses

H_{01}: There is no significant difference in the gain scores of the overall CHEAKS scores between the experimental group and the control group after the implementation of the SSI-based literacy programme.

H_{02}: There is no significant difference in awareness of plastic pollution between the experimental group and the control group after the implementation of the SSI-based literacy programme.

H_{03}: There is no significant difference in attitudes toward sustainability between the experimental group and the control group after the implementation of the SSI-based literacy programme.

H_{04}: There is no significant difference in willingness to engage in sustainable actions between the experimental group and the control group after the implementation of the SSI-based literacy programme.

Variables of the Study

Table 1 variable of the study

Type	Variable	Description
Independent Variable	Socio-Scientific Issue (SSI)-based Literacy Programme on Plastic Pollution	An instructional programme designed to develop students' understanding of plastic pollution.
Dependent Variable	a. Awareness of plastic pollution b. Attitude toward sustainability c. Willingness to take sustainable action	Measured by Children's Environmental Attitude and Knowledge Scale (CHEAKS)
Controlled Variables	Grade level, instructional content, duration of intervention	Grade 9 students content are aligned to ensure equivalence.
Intervening Variables	Student motivation, prior environmental exposure, classroom environment	Internal or contextual factors that effect SSI programme and student outcomes

Conceptual and Operational definitions:

1. Socio-Scientific Issues (SSIs)
Conceptual Definition: Socio-Scientific Issues are complex, open-ended problems that are grounded in science but involve ethical, cultural, political, and societal dimensions. They are characterized by uncertainty and controversy, requiring learners to use scientific reasoning alongside social and moral judgment (Zeidler et al., 2005; Sadler, 2011).
Operational Definition: In this study, plastic pollution is treated as a socio-scientific issue. It is presented to 9th-grade students to explore its environmental, scientific, and ethical implications.

2. Socio-Scientific Issue (SSI)-Based Literacy Programme
Conceptual Definition: SSI-based literacy refers to an instructional approach that merges science content with socio-cultural perspectives to enhance students' understanding of science in real-life contexts. It promotes higher-order thinking, decision-making, and moral reasoning (Presley et al., 2013; Zeidler, 2014).
Operational Definition: The SSI-based literacy programme in this study is a one-week educational intervention developed for Grade 9 students. It includes interactive lectures, multimedia presentations, group debates, and action-oriented tasks related to plastic pollution. The programme is designed to improve students' awareness, attitudes toward sustainability, and willingness to take environmental action, assessed using pre- and post-intervention CHEAKS scores.

3. Children's Environmental Attitudes and Knowledge Scale (CHEAKS)
Conceptual Definition: CHEAKS is a validated instrument developed by Lemming et al. (1995) to measure children's environmental knowledge and pro-environmental attitudes. It includes cognitive and affective components of environmental literacy.
Operational Definition: In this study, CHEAKS is used as the primary assessment tool to evaluate students' awareness of plastic pollution, attitudes toward sustainability, and willingness to take sustainable action. The gain scores (post-test minus pre-test) for each domain and overall score are used to determine the effectiveness of the SSI-based literacy programme.

4. Sustainable Development Initiatives
Conceptual Definition: Sustainable development initiatives refer to individual or collective actions aligned with the United Nations' Sustainable Development Goals (SDGs), particularly those focused on environmental protection, equity, and responsible consumption (UNESCO, 2017).
Operational Definition: In this study, sustainable development initiatives refer to students' expressed intentions and reported actions—such as reducing plastic use, spreading awareness, or initiating school campaigns—taken as a result of participating in the SSI-based literacy programme.

5. Environmental Awareness
Conceptual Definition: Environmental awareness is the cognitive understanding of environmental issues and the ability to recognize their causes, consequences, and possible solutions (Hungerford & Volk, 1990).
Operational Definition: In this study, environmental awareness specifically refers to students' understanding of plastic pollution, measured through the knowledge-based items of the CHEAKS instrument before and after the intervention.

6. Attitude toward Sustainability
Conceptual Definition: Attitude toward sustainability refers to a learner's disposition to value, support, and prioritize sustainable behaviors and environmental responsibility in their personal and social lives (Olsson et al., 2016).
Operational Definition: In this study, this attitude is measured through attitudinal items in the CHEAKS scale, with the difference between pre-test and post-test scores used to calculate change as a result of the intervention.

7. Willingness to Take Sustainable Action

Conceptual Definition: Willingness to act refers to the motivational and behavioral readiness of an individual to participate in environmentally responsible actions (Kollmuss & Agyeman, 2002).

Operational Definition: In this study, students' willingness to take sustainable action is measured through behavioral intent items in the CHEAKS and reflected in gain scores, indicating a change in their likelihood to engage in sustainable behaviors.

Methodology:

Research Design: The present study employed a quasi-experimental research design with a pre-test–post-test control group structure to evaluate the effectiveness of a Socio-Scientific Issue (SSI)-based literacy programme on students' environmental attitudes and knowledge, specifically related to plastic pollution for the comparison of gain scores between two groups, experimental and control. The gain scores are used to study the effectiveness of the intervention.

Population and Sample: The population consisted of 9th-grade students enrolled in grant-in-aid secondary schools within a selected district that followed a standardized science curriculum. A sample of 55 students was selected using simple random sampling from the available population to ensure that each student had an equal chance of selection. Subsequently, the students were randomly assigned to two groups:
Experimental Group (n = 28): Received a one-week SSI-based literacy programme focused on plastic pollution and its broader implications for environmental sustainability. Control Group (n = 27): Received regular science instruction aligned with the curriculum, with no exposure to SSI-related content. Both groups were comparable in terms of age, academic ability, and prior exposure to core science subjects, ensuring baseline equivalence.

Intervention: "SSI for Sustainability: A Socio-Scientific Literacy Programme on Plastic Pollution"

The Intervention Programme - "SSI for Sustainability: A Socio-Scientific Literacy Programme on Plastic Pollution" was designed as a one-week structured SSI-based literacy programme, aimed at promoting students' environmental awareness, sustainability attitudes, and responsible action concerning plastic pollution. The intervention was conducted through five consecutive classroom sessions, each lasting approximately 45 minutes, and was grounded in the principles of constructivist and experiential learning, aligned with Education for Sustainable Development (UNESCO, 2017).

Session-Wise Module Description:

Session 1: Introduction to Socio-Scientific Issues (SSI) and Plastic Pollution: Students were introduced to the concept of Socio-Scientific Issues (SSI)—real-world problems that require scientific understanding and ethical reasoning (Zeidler & Nichols, 2009). Short audiovisual materials were used to highlight plastic pollution as an urgent global issue. Students engaged in a guided classroom discussion on the relevance of plastic pollution to daily life, community, and the planet.

Session 2: Scientific Understanding of Plastics: The origin, production, chemical properties, and non-biodegradable nature of plastic were explored. Students learned about the persistence of plastics in the environment and the ecological implications of microplastics.

Session 3: Impact Analysis and Case Study: Case studies, like animals ingesting plastic from the waste were used to help students analyze the environmental, health, and social consequences of plastic use and disposal. Students engaged in group discussions and completed a cause-and-effect mapping activity.

Session 4: Solution-Oriented Thinking and Action Planning: Students worked in small groups to brainstorm actionable solutions to reduce plastic use in their homes, school, and community. Each group created SSI-based action plan, such as organizing awareness drives, refusing single-use plastic, or setting up waste segregation bins.

Session 5: Reflection and Commitment: Students shared their learnings and presented posters or pledges for sustainable action. They wrote individual reflections on what they learned and how they plan to apply it in their daily lives. This session emphasized connecting classroom learning to personal responsibility and social impact.

Ethical Considerations

Ethical consideration, including permission from the school, citations, acknowledgements before data collection, and informed consent from participants, was taken. Anonymity and confidentiality were maintained throughout the study. The voluntary nature of participation was ensured.

Data Collection and Analysis

Tool: To assess the impact of the Intervention Programme - "SSI for Sustainability: A Socio-Scientific Literacy Programme on Plastic Pollution", the Children's Environmental Attitudes and Knowledge Scale (CHEAKS) developed by Lemming, Dwyer, & Bracken (1995) was used. CHEAKS is a validated and widely recognized instrument for measuring environmental knowledge, attitudes, and behavior among school-aged children. The tool was adapted to specifically address the objectives of the current study.

The scale consisted of 30 items, equally divided into three domains: Awareness of Plastic Pollution (10 items): Measuring students' conceptual and factual knowledge. Attitude toward Sustainability (10 items): Assessing personal concern, responsibility, and values related to environmental care. Willingness to Take Sustainable Action (10 items): Capturing students' intentions and readiness to act on plastic-related issues.

Items were framed in simple and age-appropriate language to suit 9th-grade learners. A 3-point Likert-type response format (Agree – Undecided – Disagree) was used. The final version demonstrated acceptable internal consistency with a Cronbach's alpha > 0.75 across all subscales.

Data Analysis Techniques

The gain scores (post-test minus pre-test) were used to evaluate the effectiveness of the intervention. Descriptive Statistics - Means, standard deviations, and gain score distributions for both groups were used. Inferential Statistics - Independent Samples t-test was used to compare the gain scores of experimental and control groups for each variable (awareness, attitude, willingness, and overall CHEAKS score) for testing the hypothesis. Effect Size (Cohen's d) was used to determine the magnitude of the difference.

Parametric Assumptions Testing: Normality of gain score distribution (using Shapiro–Wilk test) and Homogeneity of variances (using Levene's test): To determine the appropriate statistical technique for analysing the effectiveness of the SSI-based literacy programme, the normality of the gain scores was assessed. The Shapiro-Wilk test yielded a p-value of 0.033, indicating a mild deviation from normality. However, further inspection of the distribution through skewness (0.070) and excess kurtosis (–1.15) suggested that the data was approximately symmetrical and mesokurtic, indicating a reasonably normal shape. Given the moderate sample size (n = 55), approximately equal group sizes (experimental = 28, control = 27), and absence of outliers, the dataset meets the assumptions for parametric testing.

In addition to normality, the assumption of homogeneity of variances was tested using Levene's test, which assesses whether the variances of the gain scores for the experimental and control groups are equal. The results revealed a non-significant Levene's test (F (1, 53) = 0.6609, p = 0.4199), indicating that the variances between the two groups are not significantly different. This satisfies the assumption of equal variances required for conducting an independent samples t-test. Thus, with both assumptions of normal distribution and homogeneity of variances reasonably met, it is appropriate to proceed with parametric testing, specifically the independent samples t-test, to examine the impact of the SSI-based literacy programme on students' environmental awareness, attitude, and sustainable action.

Therefore, an independent samples t-test was considered appropriate for comparing the gain scores between the experimental and control groups.

Testing of the Hypothesis:

H_{01}: There is no significant difference in the gain scores of the overall CHEAKS scores between the experimental group and the control group after the implementation of the SSI-based literacy programme.

table 2
descriptive and inferential values of CHECK scores (within groups)

Group	N	Gain	% Gain	SED (Gain)	t value (df = 27)	Cohen's d	Significance
Experimental	28	14.2	21.9%	2.90	4.32	1.28	Significant (p < .001)
Control	27	2.7	4.2%	2.80	0.96	0.31	Not Significant (p > .05)

Table 1 shows that the experimental group (n = 28) had a pre-test mean of 64.7 and a post-test mean of 78.9, resulting in a mean gain of 14.2 points (a 21.9% increase). In contrast, the control group (n = 27) had a pre-test mean of 64.5 and post-test mean of 67.2, with a gain of only 2.7 points (a 4.2% increase).
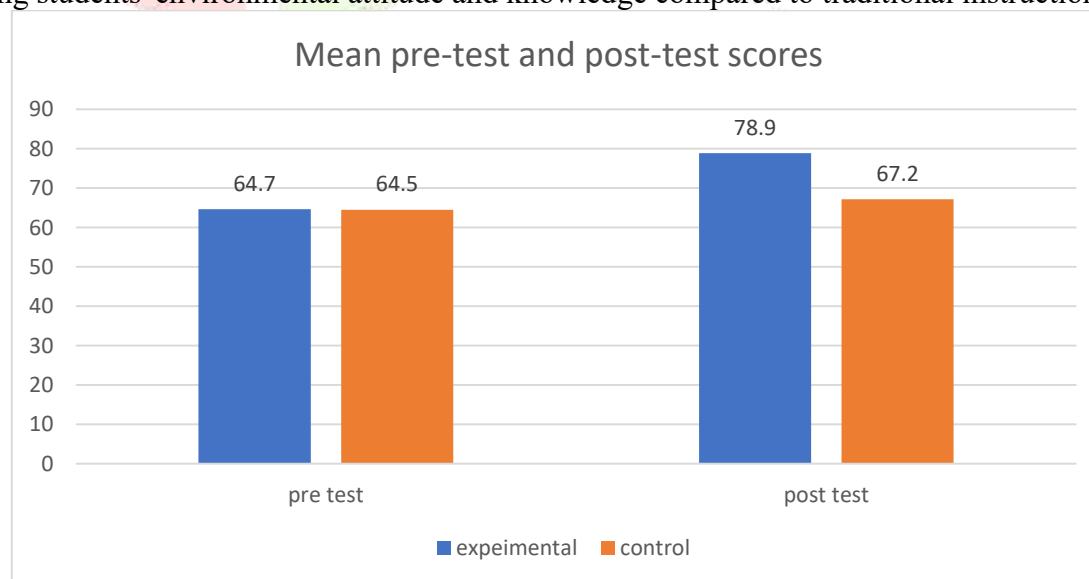
A paired samples t-test conducted within each group indicated a statistically significant difference for the experimental group, t (27) = 4.32, p < .001 (critical value ≈ 3.505 at α = 0.001). However, the difference for the control group was not significant, t (26) = 0.96, p > .05 (critical value ≈ 2.056 at α = 0.05). This suggests that the SSI-based intervention had a substantial positive effect, while traditional instruction did not produce meaningful change.

table 3
inferential statistics of gain scores (between groups)

Group	N	Gain	SED	t (df 53)	Cohen's d	Significance
Experimental	28	14.2	0.97	11.86	3.20	Significant (p < .001)
Control	27	2.7				

An independent samples t-test comparing the gain scores of the experimental group and the control group revealed a statistically significant difference, at df 53 the obtained t value was 11.86, p < .001. The standard error of the difference (SED) was 0.97, and the effect size (Cohen's d) was 3.20, which indicates a very large effect. This confirms that the SSI-based literacy programme had a strong and positive impact on students' environmental attitude and knowledge, as measured by the CHEAKS scale.

Thus, the difference in gain scores between the experimental and control groups is highly significant, and the null hypothesis (H_{01}) is rejected. The findings support the effectiveness of the SSI-based literacy programme in enhancing students' environmental attitude and knowledge compared to traditional instruction.

fig. 1: mean experimental and control group overall CHECK scores
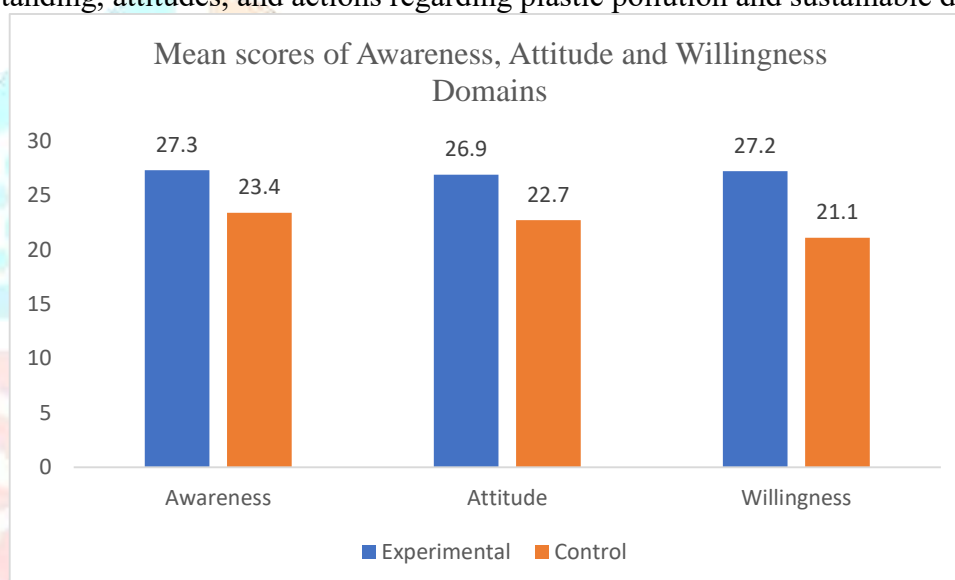
Analysis of hypotheses 2, 3, and 4

There is no significant difference in **H$_{02}$:** awareness of plastic pollution **H$_{03}$:** attitudes toward sustainability **H$_{04}$:** willingness to engage in sustainable actions; between the experimental group and the control group after the implementation of the SSI-based literacy programme.

An independent samples t-test for the gain scores was conducted to determine whether the difference in post-test scores between the experimental and control groups was statistically significant.

Table 4 Inferential Statistics of gain scores across awareness, attitude & willingness

Set	Group	Pre-Mean	Post-Mean	Gain	t-value	p-value	Significance
A (Awareness)	Experimental	21.6	27.3	5.7	4.01	< .001	Significant
	Control	21.4	23.4	2.0			
B (Attitude)	Experimental	21.5	26.9	5.4	3.86	< .001	Significant
	Control	21.3	22.7	1.4			
C (Willingness)	Experimental	21.6	27.2	5.6	4.55	< .001	Significant
	Control	21.8	21.1	-0.7			

Table 2 shows that the result indicates a statistically significant difference in the post-test scores in favour of the experimental group. This confirms that the SSI-based literacy intervention had a strong positive effect on students' understanding, attitudes, and actions regarding plastic pollution and sustainable development.

fig. 2: mean experimental and control group domain-wise cheak scores

Discussion of Results

The results of the present study provide strong evidence that the SSI-based literacy programme was effective in enhancing students' knowledge, attitudes, and behavioural intentions toward sustainability. The experimental group consistently outperformed the control group across all domains of the CHEAKS scale—overall scores, awareness of plastic pollution, attitudes toward sustainability, and willingness to engage in sustainable actions.

The statistically significant differences, coupled with large effect sizes, suggest that the intervention was not only impactful in terms of measurable learning gains but also meaningful in fostering deeper environmental consciousness. While the control group showed marginal or non-significant improvement under traditional instruction, the experimental group demonstrated substantial gains, indicating the pedagogical value of SSI-based approaches in addressing complex socio-environmental issues.

These findings align with contemporary research highlighting the effectiveness of inquiry-based, context-driven pedagogies in promoting critical thinking, environmental responsibility, and sustainable practices among students. The integration of real-world socio-scientific issues appears to engage learners more actively and meaningfully than conventional approaches, thereby supporting the broader goals of education for sustainable development as envisioned in NEP 2020.

Major Findings:

1. The SSI-based literacy programme on plastic pollution was successfully designed and implemented, demonstrating feasibility within the school curriculum and gaining active participation from 9th-grade students.
2. Post-intervention analysis using CHEAKS indicated a significant improvement in students' environmental knowledge and attitudes, with gain scores reflecting enhanced awareness and pro-environmental dispositions.
3. Students exhibited a clearer understanding of the causes, consequences, and mitigation strategies related to plastic pollution, suggesting that the programme effectively deepened their conceptual grasp of the issue.
4. The intervention fostered positive shifts in students' attitudes toward sustainability and environmental responsibility, as evidenced by greater concern for ecological balance and willingness to adopt eco-friendly practices.
5. Beyond individual learning, the programme encouraged students' readiness to engage in sustainable actions, including initiating small-scale community projects (e.g., plastic segregation drives, awareness campaigns) and advocating for responsible consumption within their families and peer groups.

Conclusion

In conclusion, the study demonstrates that the SSI-based literacy programme significantly improved students' environmental awareness, attitudes, and willingness to act toward sustainability, as reflected in the overall CHEAKS scores. The large and meaningful gains in the experimental group, compared to the negligible progress in the control group, highlight the effectiveness of socio-scientific issue-based pedagogy over traditional instruction. These findings reinforce the importance of integrating real-world issues into classroom teaching to cultivate responsible, informed, and sustainability-oriented learners.

References:

[1] Evagorou, M., Albe, V., Angelides, P., & Osborne, J. (2014). Engaging students in scientific inquiry and socio-scientific argumentation: A role for teachers' beliefs? International Journal of Science Education, 36(7), 1069–1086. https://doi.org/10.1080/09500693.2013.861047

[2] Kurniawan, T. A., Albadarin, A. B., Jern, N. W., & Jami, M. S. (2021). Revisiting plastic waste management in Southeast Asia: Education and policy perspectives. Waste Management, 121, 409–422. https://doi.org/10.1016/j.wasman.2020.12.036

[3] Kurniawan, T. A., Liang, X., Othman, M. H. D., Avtar, R., & Hwang, G. (2021). Circular economy and education for sustainable development: The role of universities. Sustainability, 13(22), 12699. https://doi.org/10.3390/su132212699

[4] Kahn, S., & Zeidler, D. L. (2017). A conceptual analysis of socio-scientific issues in science education. International Journal of Science Education, 39(1), 44–61. https://doi.org/10.1080/09500693.2016.1264648

[5] Lee, H., & Witz, K. G. (2009). Science teachers' inspiration for teaching socio-scientific issues: Disconnection with reform efforts. International Journal of Science Education, 31(7), 931–960. https://doi.org/10.1080/09500690801898903

[6] Leeming, F. C., Dwyer, W. O., & Bracken, B. A. (1995). Children's Environmental Attitude and Knowledge Scale: Construction and validation. The Journal of Environmental Education, 26(3), 22–31. https://doi.org/10.1080/00958964.1995.9941442

[7] Olsson, D., Gericke, N., & Chang Rundgren, S. N. (2016). The effect of sustainability education on students' sustainability consciousness. Environmental Education Research, 22(3), 372–389. https://doi.org/10.1080/13504622.2015.1029803

[8] Olsson, D., Gericke, N., & Chang Rundgren, S. N. (2016). The effect of implementation of education for sustainable development in Swedish compulsory schools—Assessing pupils' sustainability consciousness. Environmental Education Research, 22(2), 176–202. https://doi.org/10.1080/13504622.2015.1005057

[9] OpenAI. (2025). ChatGPT (GPT-5) [Large language model]. https://chat.openai.com/

[10] Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. Journal of Research in Science Teaching, 41(5), 513–536. https://doi.org/10.1002/tea.20009

[11] Sadler, T. D. (2011). Socio-scientific issues in the classroom: Teaching, learning and research. Springer. https://doi.org/10.1007/978-94-007-1159-4

[12] Sharma, A., & Sharma, R. (2020). Project-based environmental education: Developing ecological sensitivity in Indian schools. Journal of Education for Sustainable Development, 14(2), 124–139. https://doi.org/10.1177/0973408220955872

[13] Subramanian, S. M., & Ramanathan, A. (2018). Environmental literacy and action among Indian adolescents: A study of knowledge-behavior gap. International Journal of Environmental & Science Education, 13(4), 345–360.

[14] UNESCO. (2017). Education for Sustainable Development Goals: Learning objectives. UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000247444

[15] Zeidler, D. L., & Nichols, B. H. (2009). Socioscientific issues: Theory and practice. Journal of Elementary Science Education, 21(2), 49–58. https://doi.org/10.1007/BF03173684

[16] Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socio-scientific issues education. Science Education, 89(3), 357–377. https://doi.org/10.1002/sce.20048