



Bridging Ethnoscience and Socio-Scientific Issues: The Role of Interactive Web Media in Scientific Literacy

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Abstract: Students' poor scientific literacy in addressing socio-scientific issues is a critical challenge in 21st century science education. Innovative learning approaches are needed to meaningfully integrate ethnoscience, socio-scientific issues, and digital technology. This study investigates the effectiveness of interactive web-based learning integrating Ethnoscience and Socio-Scientific Issues (ESSI) in improving students' scientific literacy. Using a quasi-experimental non-equivalent control group pretest-posttest design. Scientific literacy was measured using validated tests and analyzed through independent sample t-tests and N-Gain analysis. The results showed that the experimental group achieved significantly higher scientific literacy than the control group (mean posttest = 82.40 vs. 74.15; $p = 0.002$), with a high N-Gain score of 0.71. The results show that web-based ESSI learning effectively enhances scientific literacy. The study concludes that interactive web-based ESSI learning effectively strengthens students' scientific literacy. This research contributes to science education by demonstrating the pedagogical value of integrating local wisdom, socio-scientific contexts, and digital media to support contextual and sustainable science learning aligned with the Sustainable Development Goals (SDGs).

Keywords: ethnoscience; interactive web media; scientific literacy; socio-scientific issues

Recommended citation: Yasir, M., Ahied, M., Wardani, E., Prahani, B. K., & Kurtuluş, U. M. A. (2026). Bridging Ethnoscience and Socio-Scientific Issues: The Role of Interactive Web Media in Scientific Literacy. *Journal of Innovation in Educational and Cultural Research*, 7(3), 483-492.

INTRODUCTION

Scientific literacy is widely recognized as a fundamental competency for citizens in the 21st century, encompassing not only mastery of scientific concepts but also the capacity to interpret evidence, assess scientific claims, and make informed decisions related to socio-scientific issues embedded in ethical, cultural, and local contexts. Contemporary science education emphasizes that scientifically literate learners should be able to meaningfully connect scientific knowledge to real-world phenomena, making science relevant and applicable to everyday decision-making. These skills are crucial for promoting responsible citizenship, especially when tackling difficult issues such as public health, environmental sustainability, and technological advancement (Chen & Liu, 2018; Liu & Tsai, 2023). At the junior high school level, science instruction plays a strategic role in cultivating these abilities early, supporting the development of conceptual understanding, critical reasoning, and problem-solving ability required for lifelong learning.

Despite its importance, empirical evidence consistently indicates that students' scientific literacy remains low, particularly when learning tasks involve socio-scientific reasoning and real-life contexts. International assessments and recent studies report persistent difficulties among students in constructing arguments, evaluating data, and applying scientific knowledge to social issues (Roberts, 2011; Zeidler & Sadler, 2023; Zohar & Nemet, 2002; Vieira et al., 2016; Rasa, 2024; Bossér, 2024). In Indonesia, students often demonstrate surface-level understanding, relying on memorization rather than analytical reasoning when confronted with socio-scientific issues such as climate change, food security, or waste management. This situation reflects a discrepancy between the intended goals of science education and actual classroom practices, indicating that the transformative potential of science learning has not yet been fully realized.

Recent literature identifies two major contributing factors to this condition. First, science instruction remains dominated by conventional approaches that isolate scientific content from students' socio-cultural realities, limiting opportunities for inquiry, discussion, and contextual reasoning (Bossér, 2024; Araiza et al., 2021). Second, although digital technologies are increasingly accessible in schools, their pedagogical use often lacks depth, functioning merely as digital substitutes for textbooks rather than as interactive environments that promote higher-order thinking and literacy of science (Arifin et al., 2025; Viehman et al., 2024; Wahab et al., 2025). These limitations suggest the need for learning innovations that integrate meaningful contexts, critical discourse, and interactive digital support.

In response, socio-scientific issues (SSI)–based learning and ethnoscience integration have emerged as promising approaches. SSI-oriented instruction has been shown to enhance scientific reasoning, argumentation, and ethical decision-making by engaging students with authentic societal problems (Verawati et al., 2025). Similarly, ethnoscience-based learning contextualizes science through local wisdom and indigenous knowledge, increasing relevance, motivation, and cultural identity in science learning (Rini et al., 2025; Yuliana et al., 2021; Baytelman et al., 2020). Separately, interactive web-based learning environments offer dynamic features such as simulations, multimodal representations, and collaborative inquiry that support student-centered and inquiry-driven learning (Setiyowati, 2021; Cahyani et al., 2024).

However, existing studies predominantly examine SSI, ethnoscience, or digital learning in isolation. Empirical research that systematically integrates ethnoscience and socio-scientific issues within an interactive web-based learning environment remains scarce, particularly at the lower secondary level and within the Indonesian context. Moreover, limited evidence explains how such integration affects specific dimensions of scientific literacy, including conceptual understanding, evidence-based reasoning, and contextual socio-scientific decision-making (Çalik et al., 2019; Dewi et al., 2021; Syahmani et al., 2024). Ethnoscience provides local cultural context and traditional knowledge, making science materials more relevant and meaningful to students (Yuliana et al., 2021; Wei et al., 2024). This study fills this gap by proposing and empirically testing an interactive web-assisted Ethnoscience–Socio-Scientific Issues (ESSI) learning model, offering a novel contribution by combining cultural relevance, critical socio-scientific discourse, and digital interactivity to strengthen scientific literacy aligned with the Sustainable Development Goals (SDGs).

The novelty of this study lies in its explicit and systematic integration of ethnoscience, socio-scientific issues (SSI), and interactive web-based digital media within a single learning framework to enhance multiple dimensions of students' scientific literacy. Unlike previous studies that tend to examine ethnoscience, SSI, or digital learning media in isolation, this research uniquely combines these three elements to simultaneously strengthen conceptual understanding, evidence-based reasoning, and decision-making in socially and culturally relevant scientific contexts. By embedding local cultural knowledge and real socio-scientific problems into an interactive web environment, this approach enables students to actively construct knowledge, interpret data, and engage in reflective inquiry grounded in their lived experiences. This integrative design represents a novel contribution to science education research, demonstrating how digital interactivity can serve not merely as a delivery tool but also as a cognitive and cultural scaffold that bridges scientific concepts with local wisdom and contemporary societal challenges.

Integrating ethnoscience and SSI into interactive web learning aligns with both pure and applied aspects of science education. On the pure science side, students develop conceptual mastery and scientific inquiry skills that reflect core disciplinary knowledge. On the applied side, they learn to contextualize these concepts to local wisdom and societal challenges, enabling them to evaluate solutions based on ethical considerations, sustainability, and community values. Thus, the ESSI approach represents a balanced educational model that builds scientific competence while fostering socio-cultural sensitivity. By blending these three elements about critical SSI discourse, contextual ethnoscience values, and the dynamic features of interactive web media, students are expected to experience meaningful learning that stimulates curiosity, engagement, and empowerment to take part in real-world problem-solving.

Based on the aforementioned justification, the current study aims to examine how junior high school students' scientific literacy can be improved through an interactive web-assisted Ethnoscience and Socio-Scientific Issues (ESSI) learning model. Specifically, this research seeks to determine the extent to which this integrated approach enhances students' conceptual understanding, evidence-based reasoning, and decision-making abilities in addressing socially and culturally relevant scientific problems and contexts. The combination is anticipated to accelerate improvements in scientific literacy, particularly in dimensions related to reasoning and decision-making in relevant social contexts. It may also strengthen the national agenda of cultivating future generations who are technologically adaptive and culturally rooted.

METHODS

The research employed a quasi-experimental method using a pre-test–post-test non-equivalent control group design, which is widely applied in educational research contexts where full randomization is impractical while maintaining internal validity (Campbell & Stanley, 2015; Aron et al., 2006). This design was considered appropriate for examining the instructional impact of Ethnoscience–Socio-Scientific Issues (ESSI) learning assisted by interactive web media in authentic classroom settings. Two intact classes were involved: an experimental group receiving Ethnoscience–Socio-Scientific Issues (ESSI) learning supported by an interactive web, and a control group receiving conventional face-to-face instruction without interactive digital media.

Pre-tests were administered to both groups prior to the intervention to assess baseline scientific literacy, followed by post-tests after the completion of the treatment to gauge learning progress (Nurmuzayyana et al., 2023; Rizki et al., 2025). The study was carried out in the even semester of 2024–2025 over approximately four weeks, consisting of one pre-testing and orientation meeting, four instructional treatment meetings, and one

post-testing meeting. The study took place at SMPN 1 Tanjungbumi, Bangkalan-Madura, East Java. This school was chosen because it is close to the ethnoscience and social science issue of microplastic pollution in the waters of Banyusangka Beach, which served as the core learning issue (refer to Figure 1). The school also met key practical requirements for interactive web-based learning, including adequate digital infrastructure (computers/laptops/tablets, internet access, LD projector) and teachers' familiarity with interactive web-based learning.



Figure 1. Issue of microplastic pollution in the waters of Banyusangka Beach

Sixty eighth-graders from two concurrent classrooms at the same junior high school made up the study sample. Two groups were created from the sample: (a) an experimental group of 30 students receiving Ethnoscience Socio Scientific Issues (ESSI) learning with interactive web support, and (b) a control group of 30 students receiving conventional learning (face-to-face learning without Ethnoscience Socio Scientific Issues (ESSI) learning with interactive web support, using conventional teaching methods such as lectures, discussions, exercises, and textbooks). The sample size was considered adequate for quasi-experimental analysis at the classroom level and aligns with similar intervention studies in science education that focus on instructional effectiveness rather than population generalization (Rizki et al., 2025).

Purposive sampling was employed to ensure comparability between groups based on prior science achievement, socio-cultural background, and classroom facilities. Although not completely randomized between individuals, the selected classes were matched for learning prerequisites, thereby strengthening internal validity. Previous methodological studies have demonstrated that non-equivalent control group designs remain robust and informative when supported by careful group matching and baseline measurement. The literature indicates that the Non-Equivalent Control Group Design (NCD) is effective despite limitations in randomization (Campbell & Stanley, 2015; Rizki et al., 2025). Figure 2 depicts the phases of the research that were conducted.

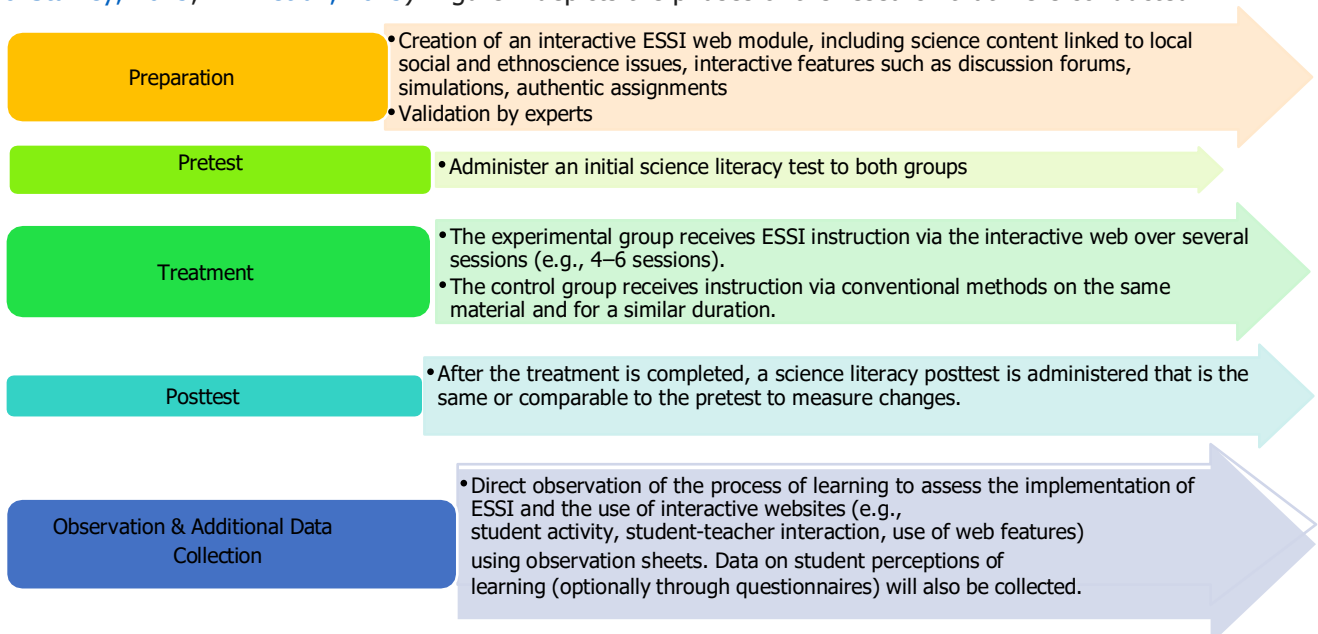


Figure 2. The stages of research

The different treatments provided to the experimental and control classes were designed to assess students' scientific literacy. Scientific literacy was measured using a validated descriptive test instrument adapted

from the OECD scientific literacy framework, encompassing three core indicators, namely explaining scientific phenomena, interpreting scientific data and evidence, and evaluating and designing scientific investigations (Zeidler & Sadler, 2023). Each indicator was operationalized through specific test items: questions on explaining scientific phenomena required students to apply scientific concepts to explain real-world issues related to local ethnoscience contexts about microplastic pollution in the waters of Banyusangka Beach; items on interpreting data and evidence involved analyzing graphs, tables, and empirical information embedded in socio-scientific scenarios; and items on evaluating and designing investigations assessed students' ability to critique scientific claims, identify variables, and propose evidence-based investigative procedures. A test of scientific literacy served as the data collection instrument. Both the experimental and control groups took this test at pre-test and post-test to ensure consistent measurement of learning gains. The six questions on the descriptive scientific literacy test were arranged sequentially according to the indicators.

The scientific literacy test data were analyzed quantitatively to determine the criteria using SPSS 26 for Windows. The Shapiro-Wilk normality test and Levene's homogeneity test were used to assess normality, and if the p-value was greater than 0.05, a normal distribution was assumed for decision-making. Paired-sample t-tests were then employed to determine statistically significant differences between pre-test and post-test scores within each group. If the calculated t-test is <0.05 , there is a difference between the pre-test and post-test after ESSI learning assisted by interactive web media. The rise in scientific literacy following treatment was assessed using a normalized gain (N-gain) test based on Hake's criteria, which include high, medium, and low gains. This statistical procedure combination provides a rigorous and transparent assessment of the effectiveness of ESSI learning-assisted interactive web in enhancing students' scientific literacy.

RESULT AND DISCUSSION

Learning innovations that integrate Ethnoscience and Socio-Scientific Issues (ESSI) with digital technology into interactive web media (<https://essi-madura.com/>). The use of this interactive web media enhances students' scientific literacy. Table 1 presents the results of the Shapiro-Wilk normality test for scientific literacy data.

Table 1. Findings from the scientific literacy data normality test

Class	Statistical	p-value	Description
Experiment	0.968	0.283	Normally
Control	0.963	0.215	Normally

Table 1 shows that the experimental class's cultural literacy data were normally distributed ($p = 0.283 > 0.05$), whereas the control class's data were not ($p = 0.215 > 0.05$). This shows that the experimental and control groups' data distributions were more reliable and consistent than the control groups'. The normal distribution in the experimental and control classes reflects that the science learning yang dirancang produced relatively uniform results and did not deviate significantly. This outcome is consistent with Dewi et al. (2021), who similarly found a normal distribution in ethnoscience-based scientific literacy studies, enabling the application of parametric tests to gauge learning effectively. The data on scientific literacy in both the experimental and control classes are normally distributed, as indicated by the normality test in Table 1 ($p\text{-value} > 0.05$). Additionally, Table 2 presents the results of the homogeneity test for scientific literacy data using Levene's test.

Table 2. Findings from the scientific literacy data homogeneity test

Test	Statistical	p-value	Description
Levene Test	1.472	0.230	Homogeneous

Table 2 shows the findings of the homogeneity test, with a p-value of 0.230 (> 0.05), indicating that the data variance between the experimental and control groups was homogeneous. This indicates that both groups come from relatively comparable populations, so that differences in achievement can be more validly attributed to the learning treatment (interactive web-assisted ESSI learning) rather than to other external factors. These results support Rizki et al. (2025), who reveal that the experimental group with the ethnoscience learning treatment had homogeneous variance with the control group, so that the difference in achievement can be attributed to the learning intervention (Rahmawati et al., 2023; Çalik & Wiyarsi, 2024; Sadler, 2011). The pre-test, post-test, and N-gain scientific literacy scores for ESSI learning facilitated by interactive online and traditional learning methods are homogeneous and normally distributed, as indicated by the homogeneity-of-variance and normality tests. Therefore, the T-Test and N-Gain can be used to gauge how well undergraduate science students' scientific literacy has improved as a result of applying ESSI learning supported by interactive web and traditional learning modes. Tables 3 and 4 display the T-Test results.

Table 3. Descriptive statistical results of scientific literacy

Groups	n	Mean	Post-test SD
Experiment (ESSI learning assisted by interactive web media)	30	82,40	6,90
Control (Conventional Learning Model)	30	74,15	7,60

Table 4. Findings from the scientific literacy T-test

t	df (Welch)	p-value (2-tailed)	Cohen's d
3,27	58	0.002	1.06

The analysis in Tables 3 and 4 indicated that the average scientific literacy score for the experimental group was 82.40 (SD = 6.90), while the control group scored 74.15 (SD = 7.60). With Cohen's $d = 1.06$, the t -test revealed a significant difference between the two groups ($t(58) = 3.27$, $p = 0.002$), indicating a large effect. This suggests that, compared with traditional instruction, the use of interactive web-based ESSI-based science learning significantly improves students' scientific literacy.

The average student's scientific literacy post-test result in the experimental class was 82.40 (SD = 6.90), while the control class scored 74.15 (SD = 7.60). The average difference of 8.25 points indicates a significant gap in achievement. This result is consistent with [Rahmawati and Maulidah \(2023\)](#), who developed digital teaching materials based on ethnoscience and achieved a considerable increase in pupils' basic science literacy compared to traditional approaches. In addition, this finding is consistent with the meta-analysis by [Çalik & Wiyarsi \(2024\)](#) and [Ningsih and Alatas \(2025\)](#), which concluded that the Socio-Scientific Issues (SSI) approach has a high effect size on scientific literacy and critical thinking. ESSI-based learning allows students to explore contextual scientific issues, such as climate change, the pollution of Banyusangka beach by non-biodegradable plastic waste threatening marine life, and the impact on fishermen, thereby meaningfully integrating scientific, social, and local values.

According to [Holbrook and Rannikmae \(2023\)](#), understanding concepts is only one aspect of scientific literacy; another is using science to solve practical issues and make moral societal decisions. The ESSI approach supports this through discussions, case studies, and evidence-based reflection that stimulate scientific thinking skills. In a local context, [Fadli et al. \(2023\)](#) found that incorporating ethnoscience grounded in local knowledge enhances scientific literacy and helps students create a welcoming learning environment.

Theoretically, this phenomenon aligns with the Experiential Learning Theory (Kolb). interactive web-assisted ESSI learning allows students to experience a learning cycle through concrete experiences (cultural exploration at Banyusangka beach), reflection, abstract conceptualization, and application, thereby increasing learning outcomes sharply. According to the Experiential Learning Theory, concrete experience, reflective observation, abstract conceptualization, and active experimentation are the four stages of the learning process ([Kolb, 1984](#)). This theory emphasizes that meaningful learning occurs when students not only receive information passively but also experience, reflect, understand, and then apply this knowledge in real contexts. The N-gain score, shown in Table 5, was then calculated from the scientific literacy pre-test and post-test findings.

Table 5. N-Gain Test Results for Scientific Literacy

Group	Experiment	Category	Control	Category
Scientific Literacy	0,71	High	0,32	Medium

There is a clear difference between the experimental and control classes' increases in scientific literacy, according to the N-Gain test results in Table 5. The control group only received an average N-Gain score of 0.32 (medium category), whereas the experimental group that employed interactive web-assisted ESSI learning had an average score of 0.71 (high category). This demonstrates that students' scientific literacy can be greatly enhanced by interactive web-assisted ESSI learning. According to this research, students' scientific literacy can be greatly increased by incorporating interactive web-assisted ESSI-based continuous science learning. These results are consistent with [Dewi et al. \(2019\)](#), who showed that ethnoscience-based learning devices can improve scientific literacy through interactive and multimodal learning experiences.

This result is consistent with the meta-analyses conducted by [Çalik & Wiyarsi \(2024\)](#) and [Ningsih and Alatas \(2025\)](#), which found that interventions based on social-scientific issues (SSI) have a large effect size in increasing students' scientific literacy compared to conventional instruction. From a theoretical perspective, these results can be explained by Social Constructivism and Digital Cognitivism. Social Constructivism (Vygotsky) explains that ESSI learning is supported by interactive, web-based learning and emphasizes collaboration, group discussion, and reflection on complex social science issues in meaningful ways. These activities align with the concept of the zone of proximal development (ZPD), where students gain knowledge through social interaction and the support (scaffolding) of teachers and peers. Meanwhile, Digital Cognitivism explained that the use of interactive web-based learning supports multimodal learning, stimulating connections among information, visualizations, and digital interactions to help students strengthen conceptual memory, reflective thinking skills,

and literacy in scientific issues. Meanwhile, the distribution of improvements in scientific literacy across four indicators in the experimental and control classes is presented in Table 6.

Table 6. Distribution of Scientific Literacy Improvements Across Three Indicators in the Experimental and Control Groups

Indicator	N-Gain	Category	N-Gain	Category
	Experimental Class		Control Class	
Explaining scientific phenomena	0,74	High	0,25	Low
Interpreting scientific data and evidence	0,72	High	0,18	Low
Evaluating and designing scientific investigations	0,70	High	0,20	Low
Average	0,72	High	0,21	Low

In Table 6, the distribution of scientific literacy improvements across three indicators provides a more detailed picture. Three indicators in the experimental class showed a high category, namely explaining scientific phenomena (0.74), interpreting scientific data and evidence (0.72), and evaluating and designing scientific investigations (0.70). Overall, the average N-Gain was 0.72 (high category). These findings indicate that interactive web-assisted Ethnoscience–Socio-Scientific Issues (ESSI) learning effectively enhances not only students' conceptual understanding of science, but also their higher-order literacy skills, including interpreting evidence, evaluating scientific claims, and linking science to social issues, ethics, local wisdom, and critical evaluation, and decision-making within socio-cultural contexts. Research support comes from [Atmojo et al. \(2025\)](#) and [Manuaba and Suyanto \(2024\)](#), who, through meta-analysis, found that ethnoscience-based learning effectively improves critical thinking skills at moderate to high levels.

Unlike previous studies that reported moderate improvements when ethnoscience or socio-scientific issues were implemented separately ([Suwono et al., 2021](#); [Haviz et al., 2024](#); [Hikmah et al., 2025](#); [Özel, 2024](#); [Kumar et al., 2023](#); [Hidayat et al., 2024](#)), this study demonstrates novelty by empirically showing that the integrated combination of ethnoscience, Socio-Scientific Issues (SSI), and interactive web technology produces a uniformly great improvement across all dimensions of scientific literacy. This synergistic effect suggests that interactive web platforms function not merely as delivery tools but as cognitive scaffolds that facilitate inquiry, data interpretation, and reflective reasoning grounded in local wisdom, supporting recent findings in journals that emphasize technology-enhanced contextual learning ([Manuaba & Suyanto, 2024](#); [Verawati et al., 2024](#); [Muliati et al., 2025](#)). In contrast, the control class, taught solely through conventional lecture methods in science, demonstrated significantly lower gains. All scientific literacy indicators fell into the low category, with an average N-Gain of 0.21. This confirms that conventional lecture-based instruction remains limited in fostering scientific literacy, particularly in skills requiring critical thinking and engagement with real-world issues. Although some improvement was observed, it was substantially lower than that of the experimental group, reinforcing previous evidence that passive instructional approaches inadequately support scientific reasoning and argumentation ([Bossér, 2024](#); [Liu & Tsai, 2023](#); [Hastuti et al., 2022](#)).

In-depth analysis of the control group also showed an increase in post-test scientific literacy compared to the pre-test. However, the increase in scientific literacy in the control group (medium) was much lower than in the experimental group (high). This indicates that conventional learning, although effective in some aspects, is not as effective as web-assisted ESSI learning in improving scientific literacy, especially in aspects that require critical thinking, making evidence-based arguments, and engaging with real-life issues. This confirms that conventional learning is passive and lacks concrete experiences, reflection, and active student involvement. From the perspective of PAIKEM theory, conventional learning tends to neglect aspects of activeness, creativity, and cultural context, thus failing to produce adequate scientific literacy outcomes ([Zeidler & Sadler, 2023](#); [Mulyono et al., 2024](#); [Husniyyah et al., 2023](#)).

The superior outcomes of the experimental class can be attributed to three key mechanisms: 1) the ESSI framework encouraged students to explain scientific phenomena using empirical evidence and socio-scientific reasoning; 2) interactive web features enabled dynamic visualization, data analysis, and simulation-based inquiry; and 3) ethnoscience contextualized learning within students' local socio-cultural realities, enhancing relevance and engagement. These results extend earlier research by [Atmojo et al. \(2025\)](#), [Tsaniyah and Fadly \(2024\)](#), and [Suryana et al. \(2021\)](#), which highlighted the role of culture and digital media separately, by demonstrating their combined effectiveness in strengthening scientific literacy aligned with Education for Sustainable Development (ESD), as supporting the goals of Sustainable Education.

By offering empirical data, this study significantly advances scientific education by demonstrating that integrating Ethnoscience–Socio-Scientific Issues (ESSI) with interactive web-based learning produces substantial and comprehensive improvements in students' scientific literacy in lower secondary education. The findings support a shift toward integrative learning designs that balance disciplinary knowledge with cultural relevance and digital innovation, serving as a strategic alternative for science learning innovation in the digital era and offering a practical pathway for achieving Sustainable Development Goals (SDGs) through contextual and

sustainable science learning. From a theoretical perspective, the findings extend constructivist and socio-cultural learning theories, which emphasize that knowledge is actively constructed through interaction with meaningful contexts and social discourse (Holbrook & Rannikmae, 2023; Bossér, 2024). The consistently great improvement across all scientific literacy indicators demonstrates that ESSI learning, supported by interactive web technology, effectively facilitates knowledge construction, scientific reasoning, and decision-making, thereby strengthening the cognitive and epistemic dimensions of scientific literacy.

From the standpoint of ethnoscience and ethnopedagogy, this study advances prior research by demonstrating that local wisdom and indigenous knowledge can be systematically embedded into digital learning environments without diminishing scientific rigor. Previous studies have shown that ethnoscience enhances relevance and cultural identity in learning but often report moderate gains when implemented through conventional media (Atmojo et al., 2025; Rini et al., 2025). The present study introduces novelty by showing that when ethnoscience is combined with socio-scientific issues and supported by interactive web features—such as simulations, data visualization, and inquiry-based tasks—it results in higher and more evenly distributed gains in scientific literacy. This finding strengthens the theoretical foundation of ethnopedagogy, which argues that culturally responsive teaching improves both cognitive outcomes and learners' sense of belonging in science education (Manuaba & Suyanto, 2024; Yasir et al., 2025; Rusmansyah et al., 2023).

In terms of learning theory application, this research aligns with inquiry-based and experiential learning frameworks, in which students learn science most effectively by engaging directly with phenomena, evidence, and real-world problems (Kolb, 1984; Mulyono et al., 2024; Hastuti et al., 2022; Jihannita et al., 2024). The interactive web-assisted ESSI model operationalizes these theories by enabling students to analyze authentic socio-scientific data, construct explanations grounded in evidence and evaluate solutions within ethical and cultural contexts. This integrative approach contributes to the growing body of Scopus-indexed literature, emphasizing that technology-enhanced inquiry environments are essential for developing higher-order scientific literacy skills in the digital era (Viehmann et al., 2024; Verawati et al., 2024; Arifin et al., 2025).

In practice, the findings offer a scalable, context-sensitive instructional model that bridges global science standards with local cultural realities. By embedding sustainability-oriented socio-scientific issues within ethnoscience-based digital learning, this research supports Education for Sustainable Development (ESD) and the Sustainable Development Goals (SDGs), particularly in fostering scientifically literate citizens capable of making informed, ethical, and culturally grounded decisions (Zeidler & Sadler, 2023; Çalik & Wiyarsi, 2024). All things considered, this study advances scientific education by showing that interactive web-assisted ESSI learning is not merely an instructional innovation but a theoretically grounded and empirically validated approach that advances scientific literacy, cultural relevance, and sustainability in contemporary science education.

The discussion in this study not only aligns the empirical findings with established theoretical frameworks such as socio-scientific issues (SSI), ethnoscience-based learning, and experiential learning but also extends prior research through a critical and comparative lens. While earlier studies have reported positive yet often moderate improvements in scientific literacy when SSI, ethnoscience, or digital media were implemented separately, this study demonstrates a more comprehensive and consistently high improvement across multiple scientific literacy indicators through their integrated application. This comparative evidence highlights a synergistic effect, whereby the combination of ESSI and interactive web media enhances not only students' conceptual understanding but also their abilities in data interpretation, scientific argumentation, and evidence-based decision-making. In contrast to previous research that emphasized isolated instructional components, the present findings suggest that interactive web platforms function as cognitive and cultural scaffolds that amplify the pedagogical strengths of SSI and ethnoscience by facilitating inquiry, reflection, and contextualization in authentic local issues. Consequently, this study contributes to science education research by empirically validating an integrative learning model that advances scientific literacy more holistically, reinforcing the importance of hybrid pedagogical designs that bridge cultural relevance, societal issues, and digital interactivity.

CONCLUSION

The study concludes that integrating interactive web media into Ethnoscience Socio-Scientific Issues (ESSI)-oriented learning effectively enhances students' scientific literacy. The novelty of this research lies in its empirical demonstration that the synergistic integration of ethnoscience, SSI, and interactive web media can yield consistently great improvements in scientific literacy, rather than the partial or moderate gains reported in studies that apply these elements separately. In terms of impact, the application of interactive web-assisted ESSI learning offers a practical and scalable model for science education that not only strengthens scientific competence but also cultivates students' cultural awareness, ethical reasoning, and responsiveness to local and global sustainability challenges. This approach supports the advancement of contextual and sustainable science education aligned with the Sustainable Development Goals (SDGs) and provides a strategic contribution to science education innovation in the digital era.

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