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The effect of an ethnoscience-based e-module on elementary students' scientific literacy

Arie Widya Murni[1*], Hikmah Luqiyah Kartikasari[1], Eviyanti Asmaul Kusnah[2], Muhammad Qasim Ali[3]
[1] Primary School Teacher Education Study Program, Universitas Nahdlatul Ulama Sidoarjo, Sidoarjo, Indonesia
[2] MI Insan Mulia Islamic Bilingual School, Sidoarjo, Indonesia
[3] University of Sialkot, Sialkot, Pakistan

*Corresponding author: ariewidya.pgsd@unusida.ac.id

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ABSTRACT

Scientific literacy has become an urgent priority in contemporary science education due to declining learning outcomes after the COVID-19 pandemic and the growing demand for competency-based reform. At the elementary level, science instruction frequently emphasizes memorization rather than reasoning, inquiry, and contextual application, which may hinder the development of foundational scientific literacy. This study aimed to examine the effect of an ethnoscience-based electronic module on elementary students' scientific literacy. A quantitative approach with a quasi-experimental pretest-posttest control group design was employed. The participants were 60 fifth-grade students from a public elementary school, selected through cluster sampling and divided into an experimental group and a control group. The experimental group learned through a structured ethnoscience-based electronic module integrating local cultural knowledge with formal scientific concepts, while the control group received conventional instruction. Data were collected using a validated and reliable scientific literacy test and analyzed using descriptive and inferential statistics. The results showed a statistically significant difference between groups, with the experimental group achieving moderate improvement (63%) compared to the low improvement of the control group (16%). The highest gain was found in interpreting data and evidence. These findings indicate that integrating cultural contextualization with structured digital learning design effectively enhances elementary students' scientific literacy. The study concludes that ethnoscience-based digital learning materials can support literacy-oriented science instruction and strengthen foundational competencies in primary education.

INTRODUCTION

Scientific literacy has become a central objective of science education in the twenty-first century (Karimah et al., 2025). It refers to students' ability to explain scientific phenomena, interpret data and evidence, and apply scientific knowledge in real-life contexts (Danchin, 2023). Despite sustained reform efforts, international large-scale assessments continue to indicate challenges in achieving this goal. The 2022 Programme for International Student Assessment (Tillah & Subekti, 2024) revealed a global decline in learning outcomes following the COVID-19 pandemic. In Indonesia, scientific literacy scores decreased by 13 points compared to 2018, closely mirroring the international average decline of 12 points, with more than half of participating countries experiencing similar setbacks (BSKAP, 2022). Although Indonesia's ranking improved relative to other countries, the decline in absolute scores confirms that strengthening students' scientific literacy remains an urgent and systemic priority.

At the elementary level, foundational scientific literacy is shaped by early learning experiences. However, science instruction frequently emphasizes memorization of definitions and formulas rather than contextual reasoning, resulting in limited conceptual understanding and weak transfer of knowledge to real-life situasion (Astuti et al., 2023; Indana et al., 2022; Pratiwi et al., 2019). Topics such as heat and temperature are often presented abstractly, limiting students' ability to connect scientific concepts with everyday phenomena (Utami & Setyaningsih, 2022; Wulandari et al., 2019). Students may recall definitions yet struggle to explain why metal feels colder than wood, why traditional food drying requires specific weather conditions, or how local cooking techniques involve heat transfer principles. This conceptual-contextual gap reflects a broader pedagogical issue in science education, where knowledge is detached from students' sociocultural environments and authentic experiences (Adim et al., 2020; Hasibuan, 2014; Sapitri et al., 2020).

In response to declining learning outcomes and the need for competency-based education, Indonesia has implemented the Kurikulum Merdeka, which emphasizes essential competencies, deeper learning, and literacy development across disciplines (Mulyati et al., 2024). Scientific literacy is positioned not merely as content mastery but as the capacity to reason scientifically, interpret evidence, and make informed decisions. However, achieving this objective requires instructional innovation that goes beyond textbook-centered teaching. Learning media must facilitate contextual exploration, inquiry, and conceptual reconstruction. Without pedagogical transformation and appropriate instructional tools, curricular reform alone may not substantially improve literacy outcomes.

One promising pedagogical pathway to bridge formal science and local knowledge is ethnoscience. Ethnoscience integrates indigenous knowledge systems and local cultural practices with formal scientific concepts, enabling students to reinterpret cultural practices through scientific frameworks (Ganesan, 2023; Smith et al., 2022). Recent work in science education also emphasizes that culturally relevant pedagogy supports science identity development and meaningful learning (Lee et al., 2025), and that local contexts can mediate deeper understanding of abstract concepts, especially in early grade science (Smith et al., 2022). Many local traditions implicitly contain scientific principles for example, food preservation techniques, salt production, or traditional cooking methods that involve thermal processes. Embedding such practices into classroom instruction situates science within students' lived experiences, fostering meaning-making and engagement.

Parallel to cultural contextualization, digital innovation plays an increasingly significant role in contemporary education. E-modules provide organized, multimedia-based, and self-paced learning environments that can facilitate visualization, guided inquiry, and reflective thinking (Paramita et al., 2025; Vitaya et al., 2025; Yeh et al., 2025; Yusuf et al., 2024). Contemporary studies show that interactive digital modules can significantly improve students' science learning outcomes and scientific reasoning skills (Elecalde et al., 2024). Prior research has demonstrated that innovative learning models and media contribute positively to science learning outcomes, including enhanced scientific literacy and higher-order thinking skills (Hidayat & Murni, 2024; Ni'mah & Murni, 2026). Research by (Audina et al., 2022; Handayani & Rokhim, 2023) also highlights that literacy-oriented instructional strategies improve students' ability to interpret science texts and scientific tasks in primary school contexts.

Nevertheless, empirical investigations that systematically integrate ethnoscience principles into structured digital e-modules and quantitatively measure their impact on elementary students' scientific literacy remain limited. Existing ethnoscience studies predominantly focus on conceptual understanding, cultural appreciation, or general academic achievement rather than specific scientific literacy competencies. Conversely, many digital learning studies emphasize product feasibility, usability, or student engagement without incorporating strong cultural contextualization or experimentally testing literacy gains. For example, (Zhu & Tang, 2023) established the validity of digital science media but did not examine its effect on scientific literacy outcomes. Similarly, (Jannah & Murni, 2022) reported increased engagement through digital learning media, yet literacy improvement was not empirically measured.

Consequently, rigorous quantitative evidence is needed to determine whether ethnoscience-based digital instructional materials can significantly enhance students' scientific literacy (Solikha & Noly, 2025), particularly at the elementary level where foundational competencies are developed. This study addresses that gap by integrating local cultural knowledge, structured digital scaffolding, and literacy-oriented assessment within a single instructional intervention, then testing its causal effect through a quasi-experimental pretest-posttest control group design. In this way, the study moves beyond product validation and engagement reporting toward evidence of measurable learning impact.

Therefore, this study aims to investigate the effect of an ethnoscience-based e-module on elementary students' scientific literacy (Buana & Citra Apriliana, 2025). The novelty of this research lies not only in combining culturally contextualized scientific content with interactive digital learning, but also in operationalizing scientific literacy through three measurable dimensions: explaining scientific phenomena, evaluating scientific inquiry, and interpreting data and evidence (Nadhifah & Jauhariyah, 2021). By aligning cultural relevance, digital innovation, and measurable literacy outcomes, this study contributes evidence-based insights toward strengthening elementary science education in the post-PISA reform era.

METHOD

This study employed a quantitative approach using a quasi-experimental method (Virgianti et al., 2026). The study applied a pretest-posttest control group procedure involving an experimental group and a control group to examine the effect of the ethnoscience-based e-module on students' scientific literacy. Both groups were administered a pretest before the intervention and a posttest after the instructional treatment. The experimental group received instruction using the ethnoscience-based e-module, while the control group received conventional instruction. This procedure enabled comparison of students' scientific literacy improvement between groups while controlling for initial differences in learning achievement (Putra et al., 2025).

The study was conducted at a public elementary school in Sidoarjo. The population consisted of all fifth-grade students distributed across three parallel classes. These classes had relatively similar academic characteristics, age range, curriculum exposure, and learning schedules because they were organized under the same school system. Since the classes had been administratively formed by the school and random assignment of individual students was not feasible in the natural classroom setting, cluster sampling was considered the most appropriate technique for selecting intact groups for the experiment. Two classes were randomly selected from the three available classes, resulting in 60 students. One class (n = 30) was assigned as the experimental group and another class (n = 30) as the control group. The use of parallel classes with comparable characteristics increased the representativeness of the sample for the fifth-grade population within the school context. Both groups were taught by the same teacher to minimize instructional variability, and the duration of instruction was equivalent.

The independent variable was the ethnoscience-based e-module, while the dependent variable was students' scientific literacy. Scientific literacy was operationally defined as students' ability to explain scientific phenomena, interpret data and evidence scientifically, and apply scientific concepts in contextual situations. These dimensions were adapted to align with elementary-level competencies and literacy-oriented assessment frameworks.

The treatment in the experimental class consisted of structured instruction using an ethnoscience-based e-module designed to integrate local cultural knowledge with formal scientific concepts. The module was presented in digital format and accessed through students' devices and classroom projection. Learning activities were organized systematically, beginning with contextual phenomena derived from local community practices, followed by guided exploration of embedded scientific concepts, conceptual clarification, and application exercises. Local knowledge was reconstructed into scientific explanations to train evidence-based reasoning rather than rote memorization. Interactive formative exercises were embedded to strengthen students' reasoning skills, interpretation of simple data representations, and contextual problem solving. The treatment was implemented over four instructional meetings (2×35 minutes per meeting). In contrast, the control group received conventional instruction using printed textbooks and teacher explanations without structured integration of ethnoscience contexts or digital interactive components.

Data were collected using a scientific literacy test administered as both pretest and posttest. The instrument consisted of 20 multiple-choice items developed based on three dimensions of scientific literacy: scientific content, scientific process, and contextual application. Content validity was established through expert judgment, and empirical validity was examined through item analysis. Reliability was calculated using Cronbach's Alpha coefficient to ensure internal consistency.

Data analysis was conducted using descriptive and inferential statistics. Descriptive statistics included mean and standard deviation calculations. Assumption testing involved normality testing using the Kolmogorov-Smirnov test and homogeneity testing using Levene's test. Students' improvement in scientific literacy was measured using the normalized gain (N-gain) formula to determine the magnitude of learning gains. Hypothesis testing was performed using an independent samples t-test to determine whether there was a statistically significant difference in scientific literacy improvement between the experimental and control groups. All statistical analyses were conducted at a significance level of 0.05 using SPSS software.

RESULTS

1. Instrument Validity and Reliability

Prior to the implementation of the experiment, the scientific literacy test instrument was validated to ensure its appropriateness and measurement accuracy. Content validation was conducted by an expert, indicating that all instructional components including the ethnoscience-based e-module, teaching materials, worksheets, and test items were categorized as valid, with validation percentages ranging from 80% to 90%. Empirical validity testing was conducted on 20 multiple-choice items administered to a pilot group. Based on Pearson correlation analysis, 12 items met the validity criteria (Sig. < 0.05), while 8 items were excluded. Therefore, 12 valid items were retained and used for both the pretest and posttest. Reliability testing using the Spearman-Brown coefficient yielded a value of 0.989, indicating excellent internal consistency. This result confirms that the instrument was highly reliable for measuring students' scientific literacy.

Table 1. Instrument Validity and Reliability Results

Component	Result	Category
Content validity	80% - 90%	Valid
Valid test items	12 items	Valid
Invalid test item	8 items	Excluded
Realiability coefficient	0.989	Very high

2. Descriptive Analysis of Scientific Literacy

Students' scientific literacy was measured through pretest and posttest scores in both control and experimental groups. Table 2 presents the descriptive statistics and normalized gain (N-gain) results.

Table 2. Descriptive Statistics and N-Gain Scores

Group	Pretest Mean	Posttest Mean	N-Gain (%)	Category
Control	60.0	66.4	16%	Low
Experimental	46.1	80.5	63%	Moderate

The control group showed a modest increase from a mean pretest score of 60.0 to 66.4 in the posttest, resulting in a low N-gain of 16%. In contrast, the experimental group demonstrated a substantial improvement, increasing from 46.1 in the pretest to 80.5 in the posttest, with a moderate N-gain of 63%. These results indicate that students who learned using the ethnoscience-based e-module experienced considerably greater improvement in scientific literacy compared to those who received conventional instruction.

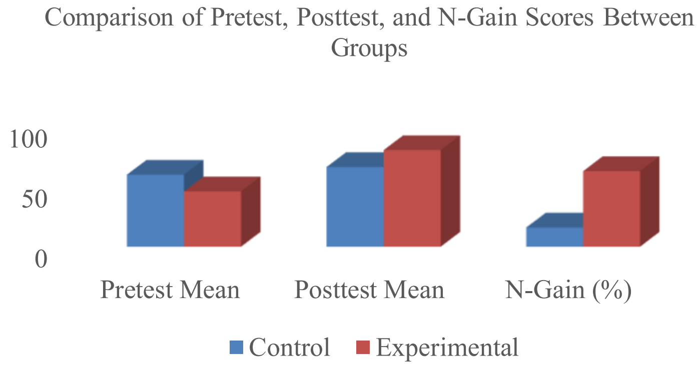

Figure 1. Comparison of Pretest, Posttest, and N-Gain Scores Between Groups

Figure 1 illustrates the comparison of students' pretest scores, posttest scores, and normalized gain percentages between the experimental and control groups the figure shows that the experimental group demonstrated substantially greater improvement after the implementation of the ethnoscience-based e-module.

3. Improvement Based on Scientific Literacy Indicators

Further analysis examined improvements across three dimensions of scientific literacy: explaining scientific phenomena, evaluating scientific inquiry, and interpreting data and evidence.

Table 3. N-Gain Based on Scientific Literacy Indicators

Indicator	Control N-Gain	Category	Experimental N-Gain	Category
Explaining scientific phenomena	0.30	Low	0.60	Moderate
Evaluating scientific inquiry	0.40	Moderate	0.60	Moderate
Interpreting data and evidence	0.10	Low	0.70	High

The greatest improvement in the experimental group occurred in the dimension of interpreting data and evidence (N-gain = 0.70), categorized as high. This finding suggests that the ethnoscience-based e-module effectively supported students in analyzing contextual scientific information and constructing evidence-based reasoning.

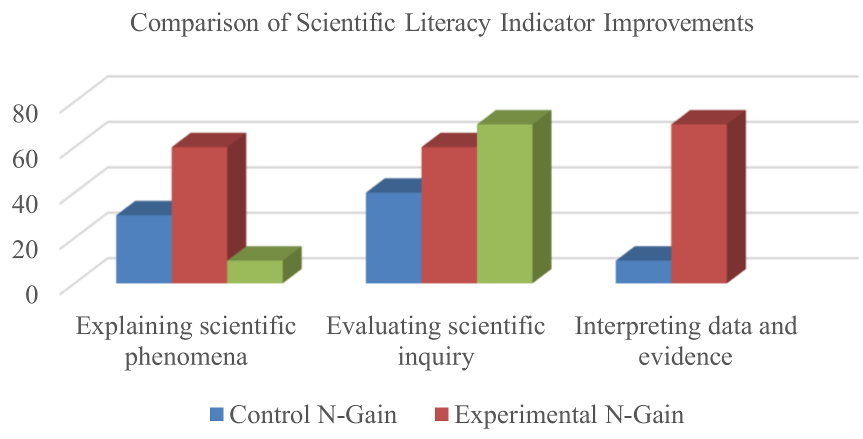

Figure 2. Comparison of Scientific Literacy Indicator Improvements

Figure 2 illustrates the comparison of N-gain scores across the three scientific literacy indicators between the control and experimental groups. The experimental group consistently achieved higher improvement in all indicators compared to the control group. The most substantial gain was found in the indicator of interpreting data and evidence, where the experimental group reached an N-gain score of 0.70 categorized as high, while the control group obtained only 0.10 categorized as low. This result indicates that the ethnoscience-based e-module effectively supported students in developing analytical reasoning, evidence interpretation, and contextual scientific understanding through culturally relevant and digitally structured learning activities.

4. Assumption Testing

Normality testing was conducted using the Shapiro-Wilk test to determine whether the data were normally distributed. The results showed that all significance values were greater than 0.05, indicating that the pretest and posttest data in both groups met the assumption of normality. Homogeneity testing using Levene's test also indicated significance values greater than 0.05 for both pretest and posttest data, confirming homogeneous variance between groups. Therefore, the data fulfilled the assumptions required for parametric statistical analysis.

Tests of Normality

	Kelas	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Hasil	Pre Test Kelas Kontrol	,133	30	,183	,942	30	,100
	Post Test Kelas Kontrol	,180	30	,014	,940	30	,090
	Pre Test Kelas Eksperimen	,160	30	,048	,939	30	,085
	Post Test Kelas Eksperimen	,150	30	,084	,942	30	,105

a. Lilliefors Significance Correction

Figure 3. Test of Normality

Figure 3, all Shapiro-Wilk significance values were greater than 0.05, indicating that the pretest and posttest data in both the experimental and control groups were normally distributed.

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
PreTest	Based on Mean	,389	1	58	,535
	Based on Median	,309	1	58	,580
	Based on Median and with adjusted df	,309	1	56,125	,580
	Based on trimmed mean	,525	1	58	,472
PostTest	Based on Mean	,001	1	58	,971
	Based on Median	,000	1	58	,987
	Based on Median and with adjusted df	,000	1	56,872	,987
	Based on trimmed mean	,002	1	58	,966

Figure 4. Test of Homogeneity of Variance

Figure 4, the significance values of the Levene's test for both pretest and posttest data were greater than 0.05, indicating homogeneous variance between the experimental and control groups.

5. Hypothesis Testing

An independent samples t-test was conducted to determine whether there was a statistically significant difference in scientific literacy between the experimental and control groups after the intervention. The analysis was performed using posttest scores from both groups.

Table 4. N-Gain Based on Scientific Literacy Indicators

Variable	Levene's Test Sig.	t	df	Sig. (2-tailed)	Mean Difference	Interpretation
Scientific Literacy Posttest	0.971	-6.334	58	0.000	-14.100	Significant Difference

The independent samples t-test yielded a significance value of 0.000 ($p < 0.05$), confirming a statistically significant difference between the experimental and control groups after the intervention. This finding indicates that the ethnoscience-based e-module significantly improved students' scientific literacy. Students in the experimental group demonstrated higher gains in scientific literacy, particularly in interpreting data and evidence, suggesting that culturally contextualized digital instruction provided meaningful support for scientific reasoning and conceptual understanding at the elementary level.

Table 5. Summary of Research Findings and Implications

Aspect	Key Findings	Implications
Statistical Effect	Significant difference between groups, t (58) = -6.334	The ethnoscience-based e-module is more effective than conventional instruction
Learning Gain	Experimental group = 63%; Control group = 16%	The intervention substantially improves students' scientific literacy
Strongest Literacy Dimension	Interpreting data and evidence	Students' reasoning, evidence evaluation, and analytical thinking were strengthened

Aspect	Key Findings	Implications
Pedagogical Contribution	Integration of cultural context, inquiry learning, and digital scaffolding	Provides an effective model for contextual and literacy-oriented science instruction
Practical Recommendation	Teachers, curriculum developers, and policymakers should adopt and scale similar innovations	Supports broader efforts to strengthen foundational scientific competencies in primary education

DISCUSSION

The findings of this study should be interpreted within the broader context of declining scientific literacy performance reported in the 2022 Programme for International Student Assessment (PISA). Post-pandemic learning loss has highlighted structural weaknesses in science instruction, particularly in fostering reasoning, evidence interpretation, and contextual application. The statistically significant difference identified in this study ($t (58) = -6.334$, $p < .001$), together with the higher normalized gain in the experimental group (63%) compared to the control group (16%), suggests that the effectiveness of the intervention was not merely caused by exposure to digital media, but by the pedagogical design embedded within the e-module. The module began with culturally familiar phenomena, enabling students to activate prior knowledge and connect abstract scientific concepts with everyday experiences. It then guided learners through structured inquiry, conceptual clarification, and contextual problem-solving tasks, which supported deeper understanding rather than rote memorization. In addition, interactive exercises and visual representations helped students process information more systematically, interpret evidence, and construct reasoned conclusions. These combined features explain why the intervention produced stronger literacy gains and provide empirical classroom-level evidence that pedagogically structured innovation can directly address broader literacy challenges.

At the national level, the implementation of Kurikulum Merdeka emphasizes essential competencies, deeper learning, and literacy integration across disciplines. Scientific literacy is framed not merely as mastery of concepts but as the ability to reason scientifically and apply knowledge in meaningful contexts (Yusuf et al., 2024). However, curriculum reform requires operational translation into classroom practice. The substantial N-gain difference between the experimental group (63%) and the control group (16%) demonstrates that literacy-oriented policy goals can be effectively realized when supported by structured, contextual, and digitally designed instructional tools.

The pedagogical shift implied by both PISA discourse and Kurikulum Merdeka involves moving from transmission-based instruction toward contextual and inquiry-driven learning. Previous studies have shown that contextual teaching approaches enhance engagement and conceptual understanding (Adim et al., 2020; Hasibuan, 2014), while local wisdom-based learning positively influences scientific literacy and learning outcomes (Sapitri et al., 2020). In line with these findings, the ethnoscience-based e-module used in this study embedded local cultural practices as entry points for scientific reasoning. This integration allowed students to connect prior knowledge with formal scientific explanations, strengthening meaning construction and cognitive engagement.

The statistical results reinforce this pedagogical rationale. The experimental group showed not only higher overall gains but the strongest improvement in the "interpreting data and evidence" indicator (N-gain = 0.70, high category). Scientific literacy in the twenty-first century emphasizes higher-order thinking, reasoning, and analytical skills (Alhusni et al., 2025). The improvement in data interpretation suggests that contextualized digital scaffolding supported students in analyzing information, understanding representations, and constructing evidence-based conclusions. These competencies are central to contemporary scientific literacy frameworks, particularly the OECD/PISA framework, which emphasizes explaining phenomena scientifically, evaluating and designing inquiry, and interpreting data and evidence scientifically (Yeh et al., 2025).

From a theoretical standpoint, the findings align with constructivist learning principles, which posit that knowledge is actively constructed through interaction with prior experience (Sholikhah et al., 2026). By reconstructing culturally familiar practices into structured scientific concepts, the e-module facilitated cognitive bridging between everyday understanding and disciplinary knowledge. Such reconstruction is crucial in elementary education, where foundational conceptual frameworks are formed and literacy habits begin to develop. Beyond confirming constructivist assumptions, the findings also suggest that ethnoscience can function as an epistemic bridge that connects community knowledge systems with formal school science, thereby extending culturally responsive science learning theory into the domain of measurable literacy outcomes.

The digital format of the module further contributed to its effectiveness. Interactive sequencing, guided inquiry tasks, and multimedia representations likely enhanced cognitive processing and supported structured reasoning. This interpretation is consistent with multimedia learning theory, which explains that combining verbal and visual information can strengthen conceptual understanding when instruction is systematically designed (Alharbi & Al-Kanaan, 2026). Prior research also indicates that contextual and problem-based approaches improve higher-order thinking and literacy performance when supported by clear scaffolding structures (Hasnunidah et al., 2015). Unlike studies that focus primarily on engagement outcomes, this research employed a quasi-experimental design with assumption testing and hypothesis testing procedures (Chung, 2026), thereby providing stronger empirical evidence that ethnoscience-based digital learning produces measurable literacy improvement.

A more critical comparison with previous empirical studies further highlights the contribution of this research. Earlier ethnoscience studies generally reported gains in conceptual understanding or attitudes toward local culture, but rarely measured specific literacy competencies using comparative experimental analysis. Similarly, many digital module studies demonstrated feasibility and student motivation without testing whether such tools significantly improve reasoning and evidence interpretation. In contrast, this study demonstrates that when cultural contextualization is combined with guided digital scaffolding, the impact extends beyond engagement toward statistically verified literacy gains. This finding supports recent international arguments that effective science innovation should integrate cultural relevance, inquiry structure, and evidence-based assessment simultaneously rather than treating them as separate instructional components (Feille et al., 2024).

At a broader level, the findings suggest that integrating local epistemologies within structured digital instruction does not conflict with global literacy standards. Instead, grounding scientific reasoning in culturally meaningful contexts appears to enhance students' capacity to meet literacy demands emphasized in international assessments. This positions ethnoscience-based digital modules as a viable model for bridging global assessment frameworks and local educational realities.

Nevertheless, several limitations must be acknowledged. The study was conducted within a single school context and over a limited instructional period, which may restrict generalizability (Chung, 2026). Future research should involve larger and more diverse samples, extended intervention durations, and exploration of mediating variables such as higher-order thinking skills and creative reasoning (Paputungan et al., 2026) to better understand the mechanisms underlying literacy improvement.

Overall, this study provides empirical support for the argument that strengthening scientific literacy requires alignment between curricular reform, contextual pedagogy, and structured digital instructional design. The ethnoscience-based e-module significantly improved elementary students' scientific literacy and offers a practical model for implementing literacy-oriented science learning in culturally diverse educational settings.

CONCLUSION

This study provides robust empirical evidence that the ethnoscience-based e-module significantly improves elementary students' scientific literacy compared to conventional instruction. The statistically significant difference between groups ($t(58) = -6.334$, $p < .001$) and the substantially higher normalized gain in the experimental group (63%) relative to the control group (16%) confirm that integrating local cultural contexts within a structured digital learning environment produces meaningful cognitive impact. The strongest improvement in the dimension of interpreting data and evidence indicates that contextualized digital scaffolding effectively strengthens analytical reasoning and evidence-based thinking, which are central competencies in contemporary scientific literacy frameworks such as the Programme for International Student Assessment. These findings directly answer the research objective by demonstrating that culturally grounded and pedagogically structured digital instruction enhances literacy outcomes at the foundational level of elementary education. Based on these results, elementary teachers are strongly encouraged to implement ethnoscience-based digital modules to promote contextual and inquiry-oriented science learning, curriculum developers should systematically embed culturally relevant scientific contexts within instructional design to operationalize competency-based reforms such as Kurikulum Merdeka, and policymakers should prioritize the development and scaling of culturally responsive digital resources to reinforce scientific literacy as a strategic educational competency.

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