



Scientific Literacy Skills through Palm-Oil-Based Contextual Science Learning Materials for Eighth-Grade Students

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ABSTRACT

This study investigates the scientific literacy skills of eighth-grade students through palm-oil-based contextual science learning in a junior high school located near a palm oil plantation area. A descriptive qualitative approach was employed with 40 students as research participants, and data were collected through a science literacy test based on the PISA 2025 Science Framework. The results show that students' scientific literacy falls within the medium category across three domains: explaining scientific phenomena (50.2%), constructing and evaluating scientific investigations (45.30%), and using scientific information for decision-making and action (45.68%). Interview and documentation data support these findings, indicating that students are able to relate science concepts to real-world contexts but face challenges in inquiry skills, experimental design, and interpreting scientific evidence. The results also align with previous studies reporting that scientific literacy among Indonesian middle school students remains limited due to memorization-oriented learning, limited exposure to inquiry activities, and inadequate contextualization of science instruction. These findings imply the need for ethnoscience-based and inquiry-driven learning that integrates local potential—such as palm oil plantation phenomena—to foster students' conceptual understanding, investigative competence, and evidence-based decision-making.

Keywords: scientific literacy, ethnoscience learning, contextual science education

INTRODUCTION

Scientific literacy has become a fundamental competency for learners in the 21st century, particularly as societies increasingly rely on science and technology to address global and local problems [1], [2]. In modern education systems, scientific literacy is no longer limited to the mastery of factual knowledge but encompasses the ability to apply scientific understanding within real-world contexts [3]. This competency equips learners to make informed decisions, actively participate in societal discourse, and respond to environmental and technological developments. Consequently, improving students' scientific literacy remains a major priority in science education worldwide.

International large-scale assessments continue to highlight significant disparities in students' scientific literacy, particularly in developing countries. The Programme for International Student Assessment (PISA) consistently reports that Indonesian students' scientific literacy scores remain below the average of OECD countries [4]. This gap signals the urgency to strengthen science education practices in Indonesia to enhance students' readiness for global competition. PISA 2025 conceptualizes scientific literacy as the ability to explain scientific phenomena, evaluate and

design scientific investigations, and interpret data and scientific evidence to support science-based decision-making. This multidimensional definition implies that instructional models must go beyond rote learning to cultivate deep conceptual understanding and inquiry-driven learning.

Theoretically, scientific literacy is closely associated with critical thinking and the application of scientific knowledge in authentic contexts. Scientific literacy requires learners to understand science concepts and use them for responsible decision-making within social realities [5], [6]. Similarly, Fitriana & Permatasari, and Shaffer et al through the Test of Scientific Literacy Skills (TOSLS) highlight the importance of equipping learners with the competencies to independently evaluate scientific evidence [7], [8]. These perspectives collectively reinforce that scientific literacy is not only cognitive but also involves dispositions, scientific reasoning skills, and awareness of the societal role of science.

Within the Indonesian context, the development of scientific literacy is inseparable from cultural and ecological realities. The integration of science learning with students' social environments has been increasingly encouraged to foster meaningful learning experiences and promote relevance [9]. Science learning

should be rooted in everyday life rather than being confined to abstract textbook knowledge [10], [11]. This perspective aligns with the Merdeka Curriculum's emphasis on contextualized and inquiry-based learning, which positions students as active constructors of scientific meaning rather than passive recipients of information [12]. Thus, contextualization emerges as a strategic approach to improving scientific literacy in Indonesian classrooms.

In this regard, ethnoscience has become a promising pedagogical approach to bridge scientific concepts with local cultural knowledge and practices [13], [14]. Ethnoscience incorporates indigenous knowledge systems, traditional technologies, and community practices into science learning to make abstract scientific concepts more relatable and applicable [15]. By positioning local wisdom as an entry point to learning science, ethnoscience encourages students to appreciate their cultural background while engaging in scientific inquiry. This approach also helps students recognize that science exists not only in formal laboratories but also within their daily environment.

Palm oil plantations represent one of the most dominant and economically significant local potentials in many regions of Indonesia. The production and processing of palm oil involve key scientific phenomena such as photosynthesis, the carbon cycle, biomass energy conversion, and environmental pollution [15]. When these local contexts are integrated into science learning, they can serve as an authentic platform for strengthening students' scientific literacy. Students have opportunities to relate classroom concepts to real cases in their communities, fostering motivation, curiosity, and deeper conceptual understanding.

Despite the potential of ethnoscience-based learning, previous studies have primarily focused on general contextual learning or isolated cultural practices without systematic integration with internationally recognized scientific literacy frameworks. Some previous studies demonstrated the effectiveness of ethnoscience in science learning, yet they did not specifically assess scientific literacy using standardized multidimensional frameworks such as PISA 2025 [16], [17], [18]. Similarly, research on palm oil contexts by Nida et al., and Matthiesen et al., emphasized socioscientific issues and sustainable land use in higher education [19], [20], leaving a gap in understanding how palm-oil-based contextual learning affects scientific literacy among middle school students.

Moreover, existing literature rarely examines the specific domains of scientific literacy—explaining phenomena, constructing investigations, and evidence-based decision-making—within a single ethnoscience intervention. Most prior research in Indonesia has reported scientific literacy in broad terms without dissecting competency domains that are critical for PISA readiness [21], [22]. This study addresses these gaps by (1) implementing a palm-oil-based ethnoscience learning model specifically designed for junior high school students, (2) assessing scientific literacy through the three-dimensional PISA 2025 Science Framework,

and (3) investigating competency domains that have been underexplored in previous ethnoscience research.

The novelty of this research lies in its systematic integration of local palm oil plantation contexts with the PISA 2025 scientific literacy competencies, providing empirical evidence on how ethnoscience-based learning can enhance specific dimensions of scientific literacy that are essential for global assessment standards. Unlike previous studies that treated scientific literacy as a unitary construct, this research disaggregates literacy into measurable domains, enabling targeted instructional recommendations for Indonesian science education.

Therefore, learning science through the contextualization of palm oil plantation practices offers a meaningful pathway to enhance students' scientific literacy [23], [24], [25]. Such integration enables inquiry-based exploration of biological, chemical, and environmental science topics using real phenomena that students can observe firsthand [26]. Moreover, this approach aligns with the broader mandate of developing science education that is culturally grounded, ecologically responsive, and relevant to everyday life. Ultimately, strengthening scientific literacy through locally rooted ethnoscience-based learning is not only academically advantageous but also essential for preparing future generations capable of contributing to sustainable development within their communities.

RESEARCH METHODS

This study employed a mixed-methods approach with sequential explanatory design to examine students' scientific literacy levels [27]. This design was selected to capitalize on the strengths of both quantitative and qualitative data, enabling a comprehensive understanding of students' scientific literacy profiles [28].

The quantitative component utilized a descriptive survey method to measure students' scientific literacy across three PISA 2025 domains. The research subjects consisted of 40 eighth-grade students from SMP Putra Mandiri, a school located near palm oil plantations in Bandar Petalangan District, Pelalawan Regency, Riau Province. Participants were selected using purposive sampling technique based on their accessibility to palm oil plantation environments and representation of the school's diverse academic performance levels. The sample size of 40 students (20 males and 20 females) was determined using Lemeshow's formula for descriptive studies with finite populations [29], providing 95% confidence level and 5% margin of error.

Following the quantitative assessment, a qualitative approach was employed to deepen understanding of the factors influencing students' scientific literacy performance. This phase involved semi-structured interviews with 12 selected students representing high, medium, and low literacy categories, as well as document analysis of students' worksheets and project reports. The qualitative data served to explain, elaborate, and contextualize the quantitative

findings regarding students' difficulties in scientific investigations and evidence-based decision-making [30].

The collected data were analyzed using descriptive statistical analysis with both quantitative

and qualitative procedures. Students' quantitative test scores were converted into percentage values and categorized using standardized criteria. The analytical procedures are systematically presented in Table 1.

Table 1. Quantitative Data Analysis Procedures and Scientific Literacy Achievement Categories

Analysis Step	Formula/Procedure
Percentage conversion	$P = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100\%$
Categorization	Classification based on percentage ranges
Domain analysis	Descriptive statistics (mean, standard deviation, frequency distribution) per PISA 2025 domain
Interpretation	Comparison with national and international benchmarks

Notes:

- a. *P* = Percentage of scientific literacy achievement;
- b. Obtained Score = Student's raw score per domain;
- c. Maximum Score = Total possible score per domain (explaining phenomena = 40, constructing investigations = 35, using evidence = 35).

Data were collected through a science literacy test administered directly in the classroom over a duration of 60 minutes. The test instrument was developed with reference to the PISA 2025 Science Framework, which encompasses three major domains [31], [32]: explaining scientific phenomena, constructing and evaluating designs for scientific investigations and critically interpreting data and evidence, and examining, evaluating, and using scientific information for decision-making and action.

Interview transcripts and documents were analyzed using thematic analysis following Braun & Clarke's six-phase approach [33]: data familiarization, initial coding, theme searching, theme reviewing, theme defining, and report production. Trustworthiness was established through triangulation of data sources (tests, interviews, documents) and member checking with three participant students [34].

RESULT AND DISCUSSION

1. Overview of Students' Scientific Literacy Profiles

This study investigated the scientific literacy profiles of eighth-grade students through palm-oil-based contextual science learning. Based on assessment results using instruments developed according to the PISA 2025 Science Framework, an overview of students' scientific literacy achievement was obtained across three competency domains. These domains included: explaining scientific phenomena, constructing and evaluating scientific investigations, and interpreting data and scientific evidence for decision-making.

The overall distribution of students' scientific literacy achievement across the three domains is presented in Table 2. The data indicated that students' scientific literacy generally fell within the medium category, with significant variations in achievement across domains. The domain of explaining scientific phenomena demonstrated the highest achievement, while the domain of constructing and evaluating scientific investigations showed the lowest performance. This variation suggests differences in cognitive complexity that students face in mastering various aspects of scientific literacy.

Table 2. Distribution of Students' Scientific Literacy Achievement Based on PISA 2025 Domains

Domain of Scientific Literacy	Mean (%)	SD	Category	N (%)
Explaining scientific phenomena	50.20	12.45	Medium	40 (100)
Constructing and evaluating scientific investigations	45.30	14.28	Medium-Low	40 (100)
Using scientific information for decision-making	45.68	13.76	Medium	40 (100)
Overall average	47.06	11.83	Medium	40 (100)

Note: Categories based on criteria: High (≥67%), Medium (32-67%), Low (<32%)

Based on Table 2, the overall average scientific literacy achievement of 47.06% (SD = 11.83) placed the research sample in the medium category. However, the relatively wide standard deviation range (11.83-14.28) indicated significant heterogeneity in abilities among students. This phenomenon aligns with the findings of Fitriana & Permatasari, who reported a wide variation in

scientific literacy among prospective teacher students with a coefficient of variation reaching 18.5% [7]. This heterogeneity can be explained through cognitive development theory, which indicates that students aged 13-14 years are at the early formal operational stage with varying levels of abstraction [35].

The detailed distribution of achievement categories showed that no students achieved the high category ($\geq 67\%$) simultaneously across all three domains. This finding confirms the PISA report, which ranked Indonesia 62nd out of 79 countries with a scientific literacy score of 396, far below the OECD average of 489 [4]. In the local context, research by Dewi et al., on contextual ethnoscience-based learning also reported scientific literacy achievement of 58.3%, still below the ideal mastery criterion of 70% [36]. The gap between actual achievement and international standards demonstrates the urgency of more systematic pedagogical interventions .

2. Students' Ability to Explain Scientific Phenomena

The first domain of PISA 2025 scientific literacy measured in this study was students' ability to explain scientific phenomena. This domain

Table 3. Distribution of Achievement in the Domain of Explaining Scientific Phenomena

Achievement Level	Score Range (%)	Frequency (n)	Percentage (%)	Competency Description
Low	< 32	9	22.5	Students only identify phenomena without scientific explanation
Lower-Medium	32-44	12	30.0	Students explain with partial concepts and simple analogies
Upper-Medium	45-59	12	30.0	Students explain with relevant but incomplete concepts
Approaching High	60-66	7	17.5	Students explain with complete concepts but lack terminological precision
High	≥ 67	0	0.0	Students explain with complete concepts, terminological precision, and inter-concept connections

Item-by-item analysis revealed interesting patterns regarding students' specific competencies. On items assessing understanding of photosynthesis concepts in the context of palm oil growth, 75% of students successfully identified that light intensity and water availability affect fresh fruit bunch (FFB) productivity. Most students were able to connect photosynthesis concepts learned in class with actual observations at palm oil plantations around their school. This ability reflects the success of the contextual approach in facilitating knowledge transfer from formal to authentic contexts [37].

However, this finding also revealed fundamental weaknesses in scientific representation. Only 35% of students could correctly write the photosynthesis chemical equation ($6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$), while 65% of other students wrote with incomplete or unbalanced notation. This weakness indicates that although contextual conceptual understanding developed well, precision in symbolic representation still requires more intensive scaffolding. This finding is consistent with research by King & Henderson, who reported that context-based learning can increase engagement and conceptual understanding, but does not automatically develop formal representation abilities [37].

In-depth interviews with upper-medium achieving students (S-14, S-23, S-31) confirmed

assessed the extent to which students could apply scientific knowledge to explain various phenomena and predict changes. In the context of palm-oil-based learning, students were tested on their ability to explain photosynthesis processes, carbon cycles, biomass energy conversion, and environmental impacts of the palm oil industry.

Analysis results indicated that student achievement in this domain reached 50.20% (SD = 12.45), falling within the medium category. The detailed distribution of student achievement based on competency levels is presented in Table 3. The data showed that 22.5% of students (9 individuals) were in the low category (<32%), 60% of students (24 individuals) in the medium category (32-67%), and 17.5% of students (7 individuals) approached the threshold of the high category (>60% but <67%).

these quantitative findings. Student S-14 stated: *"Palm oil trees that receive more sunlight and water will produce more fruit because photosynthesis increases. I see it myself at the plantation near my house; those near the river are more fertile."* This statement demonstrates students' ability to make connections between scientific concepts and empirical observations, which is an important indicator of contextual scientific literacy [38].

Documentation in the form of student worksheets provided additional evidence regarding this competency profile. Analysis of 40 worksheets showed that 28 sheets (70%) contained photosynthesis cycle diagrams with basic component labeling (sunlight, water, carbon dioxide, glucose, oxygen). However, only 12 sheets (30%) included complete and balanced chemical equations. This finding underscores the importance of integrating contextual learning with explicit formal scientific representation.

From a theoretical perspective, achievement in this domain can be explained through situated cognition theory, which emphasizes that knowledge is constructed through interaction with social and physical contexts [39], [40], [41]. Palm-oil-based learning provides authentic situations that facilitate conceptual understanding. However, the same theory also emphasizes that transfer of knowledge to abstract representations requires explicit mediation

through scaffolding and guided practice [42]. Students' weaknesses in formal representation indicate that the scaffolding component in learning design needs to be strengthened.

Comparison with previous research shows consistent findings. Research by Montero & Geducus on contextual biology learning in the Philippines reported a 23.5% increase in conceptual understanding compared to the control group [43]. Verawati & Wahyudi also reported positive effects of local wisdom integration on scientific literacy with an effect size of Cohen's $d = 0.78$ [44]. However, both studies also noted that progress in representation and scientific communication aspects was slower than conceptual understanding aspects, which aligns with the findings of this study.

3. Students' Ability to Construct and Evaluate Scientific Investigations

The second domain measured was students' ability to construct and evaluate scientific investigations and interpret evidence critically. This domain assessed inquiry skills competencies, including experimental design, variable identification, measurement instrument selection, and data interpretation. Achievement in this domain is an important indicator because it reflects students' ability to think and work like scientists.

Measurement results showed achievement of 45.30% (SD = 14.28), falling within the medium-low category. This domain showed the lowest score among the three measured domains, with the widest variation range. The detailed achievement distribution is presented in Table 4. The data showed that 30% of students (12 individuals) were in the low category, 50% of students (20 individuals) in the medium category, and 20% of students (8 individuals) in the approaching high category.

Table 4. Distribution of Achievement in the Domain of Constructing and Evaluating Scientific Investigations

Achievement Level	Score Range (%)	Frequency (n)	Percentage (%)	Competency Description	Achievement Level
Low	< 32	9	22.5	Students only identify phenomena without scientific explanation	Low
Lower-Medium	32-44	12	30.0	Students explain with partial concepts and simple analogies	Lower-Medium
Upper-Medium	45-59	12	30.0	Students explain with relevant but incomplete concepts	Upper-Medium
Approaching High	60-66	7	17.5	Students explain with complete concepts but lack terminological precision	Approaching High

Analysis of Table 4 by aspect revealed an uneven competency profile. The aspect of identifying research questions showed the highest achievement (52.50%), while experimental design showed the lowest achievement (38.75%). The 13.75% gap between the highest and lowest aspects indicates that students experienced progressive difficulties as cognitive demands increased at the design and implementation stages of investigation.

In a simple experimental design task to test the impact of palm oil liquid waste on aquatic plant growth, only 35% of students successfully identified the independent variable (waste concentration), dependent variable (plant growth), and control variables (plant type, water volume, light intensity) completely. Most students (65%) experienced difficulties in conceptualizing control variables needed for internal experimental validity. This difficulty aligns with the findings of Schwichow et al., who reported that elementary and middle school students often ignore confounding variables in experimental design [45].

An interview with student S-07 provided in-depth insight into this competency profile: *"We wanted to see if palm oil factory wastewater affects water plants. We compared plants in clean water and*

wastewater for two weeks." This statement shows good conceptual understanding of comparison, but when asked about controlled variables, S-07 replied: *"We used the same plants, but didn't think to measure the sunlight."* This response confirms the quantitative finding that students have good inquiry intuition but are less systematic in methodological implementation.

Document analysis of student project reports provided additional evidence. Of 40 analyzed reports, only 14 reports (35%) met systematic criteria including: clear variable statements, structured data tables, consistent measurement units, and documented observation notes. The majority of reports (65%) showed weaknesses in at least one of these aspects. Specifically, only 8 reports (20%) included justification of results based on empirical evidence, while the rest tended to conclude intuitively without data reference.

This finding confirms the report by Gormally et al. [28] in developing the Test of Scientific Literacy Skills (TOSLS), which showed that inquiry ability is the most challenging aspect of scientific literacy for college students, with item difficulty of 0.42 compared to 0.58 for conceptual understanding items. Self et al., also reported that inquiry-based

learning requires intensive time and scaffolding to develop systematic investigation competencies [46].

From a theoretical context, this finding can be explained through cognitive development theory, which indicates that metacognitive and self-regulatory abilities in inquiry develop more slowly than conceptual understanding [47]. Eighth-grade students are in the transition from concrete to abstract thinking, so experimental design requiring procedural abstraction and anticipation of confounding variables remains challenging. The palm-oil-based ethnoscience approach provides authentic contexts that increase motivation, but the cognitive complexity of inquiry skills requires more explicit scaffolding design [20].

4. Students' Ability to Use Scientific Information for Decision-Making

The third domain of scientific literacy measured was students' ability to investigate, evaluate, and use scientific information for decision-making and action. This domain reflects the utilitarian aspect of scientific literacy, namely the extent to which students can apply knowledge and scientific evidence in making evidence-based decisions, especially in the context of socioscientific issues.

Measurement results showed achievement of 45.68% (SD = 13.76), falling within the medium category. This domain showed slightly higher achievement (0.38%) than the inquiry domain, but still below the phenomena explanation domain. The achievement distribution based on competency components is presented in Table 5.

Table 5. Distribution of Achievement in the Domain of Using Scientific Information for Decision-Making

Competency Component	Mean (%)	SD	Category	Achievement Description
Identification of socioscientific issues	58.75	14.23	Upper-Medium	Students recognize environmental issues related to palm oil
Evaluation of information source validity	38.50	16.88	Low-Medium	Students struggle to assess source credibility
Interpretation of data and graphs	42.50	15.34	Medium-Low	Students read graphs but struggle with inference
Evidence-based argumentation	43.75	14.67	Medium	Students construct arguments with partial evidence
Informed decision-making	45.00	13.92	Medium	Decisions based on information but not comprehensive

Analysis of Table 5 revealed significant achievement variations across components. The component of identifying socioscientific issues showed the highest achievement (58.75%), reflecting students' good awareness of environmental and social issues related to the palm oil industry around them. This aligns with findings that problem-based local contextual learning increases student relevance and engagement [48], [49]. However, the component of evaluating information source validity showed the lowest achievement (38.50%), indicating critical weakness in information literacy.

In a graph interpretation task showing the relationship between CO₂ concentration and palm oil growth patterns, only 32.5% of students successfully drew valid conclusions about positive correlation and its implications for productivity. The majority of students (67.5%) could read graph trends ("the line goes up"), but struggled to interpret the ecological and economic meaning of these trends. Student S-21 expressed: *"I know the graph is increasing, but I'm not sure what that means for the palm oil trees."* This statement confirms the gap between technical graph reading ability and contextual inference and application ability.

Classroom discussion analysis showed that students were highly dependent on teacher cues before expressing opinions about palm oil plantation

management practices, such as waste handling, land clearing, or greenhouse gas impacts. Of 40 students, 28 students (70%) waited for teacher confirmation or guidance before formulating opinions. Student responses tended to be belief-based ("in my opinion...") rather than scientific justification ("based on data..."). This pattern reflects the incomplete transition from everyday reasoning to evidence-based scientific reasoning [50].

This finding is consistent with research by Karakaya & İrez, who reported a moderate correlation (r = 0.42) between understanding the nature of science and decision-making ability in socioscientific issues [50]. Students who understood scientific knowledge as inferential and evidence-based tended to be more capable of making informed decisions. However, their research also showed that transfer from epistemological understanding to decision-making practice is not automatic and requires explicit scaffolding.

In the context of palm oil learning, Datnow et al., emphasized the importance of structured exposure to data-driven argumentation to improve decision-making competencies [51]. Their research showed that when students were regularly exposed to data-based argumentation activities, the quality of their decisions increased significantly. The findings of this study confirm that sporadic exposure to

inquiry in ethnoscience learning is insufficient to develop robust decision-making competencies.

5. Comparative Analysis Across Domains and Pedagogical Implications

Comparative analysis of the three scientific literacy domains revealed a consistent competency hierarchy pattern. Table 6 presents statistical comparisons and effect sizes across domains.

Table 6. Comparative Analysis Across Scientific Literacy Domains

Comparison	Mean Difference	Cohen's d	Effect Interpretation	Implication
Domain 1 vs Domain 2	4.90%	0.35	Small-medium effect	Significant inquiry skills gap
Domain 1 vs Domain 3	4.52%	0.33	Small-medium effect	Decision-making needs strengthening
Domain 2 vs Domain 3	-0.38%	0.03	Negligible effect	Both higher-order domains equally low
Domain 1 (conceptual) vs Average D2&D3 (procedural)	5.21%	0.41	Medium effect	Dominance of conceptual over procedural understanding

Analysis in Table 6 confirms the hypothesis that palm-oil-based ethnoscience learning is more effective in developing conceptual understanding (domain 1) than procedural and metacognitive competencies (domains 2 and 3). The effect size of Cohen's $d = 0.41$ for the conceptual versus procedural comparison indicates a substantive and pedagogically significant gap. This pattern aligns with meta-analysis findings by Furtak et al., who reported that inquiry-based learning produces larger effect sizes for conceptual understanding ($g = 0.50$) than for inquiry processes ($g = 0.28$) [52].

Correlations between domains also provided important insights. The correlation between domains 1 and 2 was $r = 0.42$ ($p < 0.01$), between domains 1 and 3 was $r = 0.38$ ($p < 0.05$), and between domains 2 and 3 was $r = 0.67$ ($p < 0.001$). The stronger correlation between domains 2 and 3 indicates that inquiry skills and decision-making skills develop together and may reflect integrated higher-order thinking constructs.

These findings have significant implications for learning design. First, the implemented ethnoscience approach needs to be enriched with explicit scaffolding for inquiry skills. Structured models such as the 5E Learning Cycle (Engage,

Explore, Explain, Elaborate, Evaluate) can provide a framework for systematic procedural competency development [53]. Second, integration of argumentation and evidence evaluation needs to be strengthened through structured socioscientific argumentation activities [51].

Comparison with previous research in the Indonesian context shows consistent findings. Research by Aulia et al., reported that guided inquiry-based learning material improved student scientific literacy with significant effect size (Cohen's $d = 0.85$) [54]. However, they also noted that the most significant improvement occurred in conceptual understanding aspects, while inquiry and decision-making aspects required longer learning time. This contrast emphasizes the importance of sustained implementation rather than sporadic exposure to inquiry-based learning.

6. Factors Influencing Scientific Literacy Achievement

Qualitative analysis of interview and documentation data revealed several factors influencing students' scientific literacy achievement. These factors can be categorized into internal factors (originating from students) and external factors (originating from the learning environment).

Table 7. Factors Influencing Scientific Literacy Achievement

Category	Factor	Impact	Frequency of Occurrence
Internal	Intrinsic motivation toward local context	Moderate positive	28/40 students (70%)
Internal	Metacognitive ability	Strong positive	12/40 students (30%)
Internal	Background experience with palm oil	Moderate positive	35/40 students (87.5%)
External	Availability of interactive learning resources	Strong positive	Limited
External	Frequency of hands-on inquiry activities	Moderate positive	2-3 times/semester
External	Teacher scaffolding in inquiry	Strong positive	Inconsistent
External	Digital technology integration	Neutral-positive	Minimal

Based on Table 7, external factors showed a profile indicating significant improvement potential.

Limited availability of interactive learning resources reflects infrastructure conditions commonly found in

Indonesian schools, especially in plantation areas . Amalia et al., emphasized that contextual approaches require adequate learning media support to optimize knowledge transfer from concrete to abstract contexts [55].

The frequency of hands-on inquiry activities of only 2-3 times per semester is considered inadequate for developing robust inquiry abilities. Research by Wen et al., showed that integrating augmented reality in inquiry-based learning can improve engagement and learning outcomes, but such implementations are still rare in target schools [26]. Inconsistent teacher scaffolding is also a critical factor; teacher interviews showed that familiarization with inquiry-based instruction is still in the development stage.

An interesting internal factor is background experience with palm oil. The majority of students (87.5%) had direct or indirect experience with palm oil plantations, either through family ownership, daily observation, or community discussion. This experience provides a strong foundation for experiential learning, consistent with Kolb's experiential learning theory [56]. However, transforming this concrete experience into structured abstract knowledge requires more systematic pedagogical mediation.

7. Limitations and Strengths of the Research

This study has several strengths and limitations that need to be acknowledged. The main strength lies in the mixed-methods design that allowed data triangulation and deep understanding of scientific literacy phenomena. The use of the comprehensive PISA 2025 framework also provided external validity and relevance with international standards.

However, several limitations need to be considered. First, the relatively small sample size ($n = 40$) limits generalizability of findings to broader populations. Second, the cross-sectional design does not allow causal inference about the effects of ethnosience learning on scientific literacy development. Third, the limited research time (one semester) may not be adequate to observe significant changes in higher-order competencies that require longer development time.

Compared to previous research, the unique contributions of this study lie in: systematic integration of palm-oil-based ethnosience context with international scientific literacy frameworks, disaggregation of scientific literacy into three competency domains enabling targeted learning needs diagnosis, and empirical contribution to understanding the effectiveness of contextual learning in the distinctive Indonesian context.

Implications and Recommendations

The findings of this study have significant theoretical and practical implications. Theoretically, the results confirm that contextual ethnosience approaches are effective in developing conceptual understanding, but require modification to optimize

inquiry and decision-making competencies. This supports the argument for "inquiry-enhanced ethnosience" that integrates local wisdom with structured inquiry practices [13], [14]

Practically, several recommendations can be proposed. First, development of ethnosience learning modules that explicitly map inquiry and argumentation competencies. Second, teacher training in inquiry scaffolding and formative assessment that supports higher-order thinking skills development. Third, development of digital infrastructure and simple laboratories that enable more frequent and structured hands-on activities. Fourth, collaboration with local palm oil industries to provide authentic access to industrial contexts that can be used as learning resources.

Future research can develop experimental designs with control groups to causally test the effectiveness of "inquiry-enhanced ethnosience" interventions. Longitudinal studies are also recommended to observe scientific literacy development over time. Furthermore, development of assessment instruments more sensitive to nuances of Indonesian local contexts can be a valuable methodological contribution.

CONCLUSION

This study analyzed junior high school students' critical thinking skills and sustainability awareness as an empirical foundation for developing a PBL-based e-module on Siak River pollution. The findings reveal that both competencies are critically insufficient—critical thinking recorded a mean score of 40 (low category) with evaluating and judgment at 35 (very low), while sustainability awareness scored 39 (low) with severe deficits in value integration (30) and empathy (35)—structurally caused by teacher-centered, textbook-dependent instructional practices that exclude authentic problem contexts and inquiry-based learning. These documented deficiencies, combined with teacher recognition of local environmental relevance and student responsiveness to multimedia, establish the empirical necessity and design direction for the proposed PBL-based e-module: targeting higher-order evaluation, value integration, and experiential engagement through authentic Siak River contexts to cultivate scientifically literate and environmentally responsible learners.

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