TA'DIB JOURNAL, 28 (2), 2025, (July-December)

ISSN: 1410-8208 (*Print*) 2580-2771 (*Online*)
Available online at https://ejournal.uinmybatusangkar.ac.id/ojs/index.php/takdib/index

Culturally Responsive Community-Based Inquiry to Enhance Basic Scientific Literacy in Indigenous Papua Border Elementary Schools

Received: 04-12-2025; Revised: 10-12-2025; Accepted: 11-12-2025

Aisyah Ali*)
Universitas Cenderawasih, Indonesia
E-mail: aisyahali@fkip.uncen.ac.id

Akhmad Kadir
Universitas Cenderawasih, Indonesia
E-mail: akhmaduncen@fisip.ac.id

Ria Ristiani
Universitas Cenderawasih, Indonesia
E-mail: auliyahria@gmail.com

*) *Corresponding Author*

Abstract: This study investigates the effectiveness of a community-based, culturally responsive science learning model in improving basic scientific literacy among elementary students in the Indonesia–Papua New Guinea border region. The research addresses the persistent problem of low scientific literacy, which is largely caused by instructional practices that overlook the ecological and cultural contexts of Indigenous Papuan communities. Using a one-group pretest–posttest design, the study involved 89 students from three Indigenous community schools. A culturally adapted 12-item instrument was employed to assess five dimensions of scientific literacy: conceptual knowledge, scientific processes, scientific ethics, attitudes toward science, and scientific behaviors. Data were analyzed using Shapiro–Wilk tests, paired t-tests or Wilcoxon signed-rank tests, N-Gain scores, and effect sizes. Results demonstrated statistically significant improvements across all dimensions ($p < 0.001$). N-Gain values ranged from 0.31 to 0.36, indicating moderate learning gains, while effect sizes fell within the small-to-moderate range. These findings show that integrating local ecological practices—particularly through sago-based inquiry activities—and involving Indigenous community members meaningfully enhanced students' engagement, conceptual understanding, and reflective scientific behaviors. The study concludes that a culturally grounded community-based instructional approach contributes to more equitable, contextually relevant, and sustainable science education in Indigenous and borderland school settings.

Abstrak: Penelitian ini bertujuan menganalisis efektivitas pembelajaran sains berbasis komunitas dengan pendekatan responsif budaya dalam meningkatkan literasi sains dasar siswa sekolah dasar di wilayah perbatasan Indonesia–Papua Nugini. Permasalahan utama yang ditangani adalah rendahnya capaian literasi sains siswa yang disebabkan oleh pendekatan pembelajaran yang kurang relevan dengan konteks ekologis dan budaya masyarakat adat Papua. Menggunakan desain one-group pretest–posttest, penelitian ini melibatkan 89 siswa dari tiga sekolah komunitas adat. Instrumen literasi sains terdiri dari 12 butir yang telah diadaptasi secara kultural dan mencakup lima dimensi: pengetahuan konseptual, proses sains, etika sains, sikap terhadap sains, dan perilaku ilmiah. Analisis data dilakukan melalui uji normalitas Shapiro–Wilk, paired t-test atau Wilcoxon signed-rank, N-Gain, serta ukuran efek. Hasil penelitian menunjukkan peningkatan signifikan pada seluruh dimensi literasi sains dengan nilai $p < 0{,}001$. N-Gain berada pada kategori sedang, yakni 0,31–0,36, sedangkan ukuran efek berada pada kategori kecil–sedang. Temuan ini menunjukkan bahwa integrasi praktik budaya lokal, terutama melalui kegiatan investigasi ekologi sagu dan keterlibatan aktif komunitas adat, mampu memperkuat pemahaman konsep, menumbuhkan sikap ilmiah, serta mendorong perilaku sains yang lebih reflektif dan kontekstual. Penelitian ini menegaskan kontribusi model pembelajaran berbasis komunitas terhadap pengembangan pembelajaran sains yang lebih relevan, adil secara epistemik, dan adaptif terhadap kebutuhan sekolah-sekolah di wilayah perbatasan.

Keywords : *Basic Scientific Literacy, Culturally Responsive Teaching, Indigenous Communities, RI–PNG Border Schools, Papua*

INTRODUCTION

The RI–PNG border region, particularly Skouw, is characterized by a complex sociocultural environment where local ecological knowledge and Indigenous traditions remain well preserved. Despite this cultural richness, the region continues to experience significant educational challenges, including low achievements in foundational literacies. National assessments report that only 36.1% of third-grade students in Papua meet expected reading comprehension standards (You, 2023), signaling broader systemic concerns in science literacy development.

Basic scientific literacy in Papua exhibits similar conditions, where instruction still largely emphasizes factual recall rather than cultivating inquiry skills, critical reasoning, and understanding the interactions among science, technology, and society (Mumba et al., 2006). This imbalance is particularly detrimental in border regions, where instructional approaches often neglect the sociocultural realities of Indigenous contexts, resulting in low learning engagement.

Disparities in science education quality in the RI–PNG border region arise not only from infrastructure limitations but, more crucially, from curriculum approaches that are poorly aligned with the ecological and cultural contexts of Indigenous Papuan communities. Paradoxically, these communities maintain strong ecological practices—such as sago cultivation—that hold high potential as contextualized science learning resources. However, this cultural capital remains significantly underutilized in formal science education.

A homogenized national curriculum contributes further to students' disengagement, where science learning becomes abstract and disconnected from everyday life. Moreover, the minimal involvement of community members as educational partners widens the divide between scientific concepts and local ecological wisdom, hindering the internalization of scientific values relevant to sustainability in Indigenous environments.

Empirical studies consistently report how conventional science instruction marginalizes students' cultural experiences and leads to weaker cognitive and affective engagement (Gumbo et al., 2021; Medina-Jerez, 2008; Opoku & James, 2021). Similarly, Aberšek et al. (2015) argue that even digital-native students require explicit educational structures to develop scientific literacy. Therefore, instructional models must authentically integrate scientific knowledge with lived experiences of Indigenous communities to support meaningful learning.

Community-based culturally responsive teaching (CRT) is considered a promising approach, as it purposefully incorporates Indigenous knowledge into scientific inquiry (Gay, 2018; Idrus & Sohid, 2023). In Skouw, where sago is central to food security and ecological life, community-informed inquiry-based methods offer holistic improvements across cognitive, affective, and behavioral domains of science literacy.

Previous CRT initiatives have demonstrated improved learning relevance (Gay, 2018; Johnson, 2022). However, many such implementations remain superficial or symbolic, where Indigenous culture is treated merely as an "add-on" rather than a legitimate epistemological foundation (Idrus & Sohid, 2023). This gap limits meaningful impacts on student learning and fails to rectify epistemic marginalization.

Place-based literacy models have shown potential in bridging cultural boundaries (Ballard et al., 2023). However, formal schooling still frequently disregards Indigenous ecological knowledge as a valid scientific framework (Medina-Jerez, 2008; Sotero et al., 2020). A research gap remains in developing models that:

1) position Indigenous communities as co-constructors of science education, and
2) operationalize epistemic justice within primary school instruction.

Basic scientific literacy consists of five interconnected competencies: conceptual understanding, scientific processes, scientific ethics, attitudes toward science, and scientific behaviors (Osborne & Allchin, 2024). These competencies rarely develop optimally in marginalized border communities due to culturally detached instruction (Kumblathan et al., 2025), whereas contextualized, culturally grounded learning has shown measurable positive impacts (Ali & Kulimbang, 2025; Bektiarso et al., 2024).

Therefore, the present study contributes a deeper form of culturally responsive pedagogy: Indigenous community-based inquiry learning, which does not merely utilize culture as a context, but elevates it as an epistemic partner in building scientific understanding. This aligns with Freire's critical pedagogy that positions learners and communities as active agents of knowledge production rather than passive recipients (Freire, 1970; Nugraha et al., 2024) .

The novelty of this study lies in testing a model that operationalizes epistemic justice in an elementary science setting by engaging elders, parents, and local knowledge holders as co-producers of curriculum and epistemology, not merely cultural informants. This approach introduces a transformative shift from traditional CRT toward equitable epistemic partnerships in school science.

Furthermore, the study utilizes a 12-item culturally adapted scientific literacy instrument that integrates Indigenous knowledge systems and school science. Each dimension comprises 2–3 items in Likert-scale and closed-ended formats. The adaptation process involved iterative collaboration with Indigenous educators, ensuring linguistic appropriateness, cultural resonance with sago ecology, and conceptual equivalence through expert judgment.

Collectively, this research not only addresses the persistent science literacy gap in the RI–PNG border region but also demonstrates a methodological advancement in measuring science literacy within Indigenous epistemologies. This, in turn, offers an empirically tested model of community-driven CRT that is scalable, contextually grounded, and theoretically aligned with postcolonial and critical pedagogical traditions..

METHOD

This study employed an explanatory sequential mixed-methods design integrating quantitative and qualitative data collection and analysis in two consecutive phases (Creswell, 2009). The mixed approach enabled quantitative results to guide the focus of qualitative exploration, while qualitative insights provided contextual explanations for the observed statistical changes. This design was selected to rigorously examine both the measurable effects and the underlying learning mechanisms of culturally responsive science instruction in Indigenous border communities.

The participants consisted of all 89 students enrolled in Grades IV and V at three Indigenous community elementary schools in Skouw, Papua, located in the (RI–PNG) border area. The complete enumeration sampling was used because the total population was small and represented a single accessible cohort. Thus, separating students into experimental and control groups was neither practical nor ethically justifiable. All participants came from Indigenous households that maintain traditional sago-based subsistence practices, ensuring an authentic community-cultural context for the intervention.

Basic scientific literacy was assessed using a 12-item instrument developed specifically for this study, grounded in scientific literacy frameworks (AAAS, 1989; Bauer, 2015). Each of the five dimensions—conceptual knowledge, scientific processes, scientific ethics, attitudes toward science, and scientific behaviors—was operationalized through 2–3 culturally contextualized Likert-scale items. The instrument underwent a rigorous cultural adaptation process involving iterative consultations with Indigenous educators to ensure contextual accuracy, familiarity with local terms (e.g., "sago offshoots"), and alignment with community practices. All items were translated into the local Papuan language and back-translated to ensure linguistic equivalence.

Content validity was verified through expert judgment by a panel of five evaluators (two science education professors, two Indigenous teachers, and one traditional ecological knowledge holder), with all items meeting the minimum Aiken's V coefficient of 0.78. Internal consistency reliability (Cronbach's alpha = 0.72–0.84) demonstrated acceptable psychometric properties. Quantitative data were collected using pretests and posttests administered before and after an eight-week intervention. The intervention followed a structured inquiry-based learning cycle: (1) field exploration of sago ecosystems, (2) guided questioning and data collection, (3) collaborative analysis and explanation, and (4) student-produced scientific artifacts, such as ecosystem maps and reflective journals. Indigenous elders contributed direct cultural knowledge during field sessions to ensure integration of scientific concepts and traditional ecological practices.

Qualitative data were obtained through semi-structured interviews with nine teachers and six Indigenous community leaders, participatory classroom and field observations (24 sessions, 60–90 minutes each), and documentation of student artifacts. Thematic analysis followed Miles and Huberman (2014), employing open, axial, and selective coding with NVivo 12 assistance. Credibility measures included triangulation of multiple data sources, prolonged engagement during the intervention, and member checking with educators and community leaders. Quantitative and qualitative findings were integrated using joint display analysis to support meta-inferences (Fetters & Tajima, 2022).

RESULTS AND DISCUSSION

Quantitative Results

Descriptive Statistics and Assumption Testing

Table 2 shows that all dimensions experienced increases from pretest to posttest. Although the gains appear numerically modest, they indicate consistent improvement across conceptual, procedural, ethical, affective, and behavioral domains of basic science literacy. Such uniformity suggests that the learning model supported balanced literacy development, rather than enhancing cognitive elements alone. However, the small standard deviations indicate limited score variation, which may reflect ceiling effects or constraints in item difficulty—this warrants refinement of item complexity in future studies..

Table 1.
Descriptive Statistics of Pretest and Posttest Scores per Basic Science Literacy Dimension)

Dimensions	Mean Pretest (SD)	Mean Posttest (SD)	Mean Gain
Conceptual Knowledge	2.68 (0.51)	3.01 (0.54)	0.33
Scientific Processes	2.72 (0.49)	3.04 (0.52)	0.32

Scientific Ethics	2.81 (0.56)	3.12 (0.57)	0.31
Attitudes Toward Science	2.74 (0.53)	3.09 (0.55)	0.35
Scientific Behaviors	2.79 (0.54)	3.15 (0.56)	0.36

The Shapiro–Wilk test results (Table 3) confirmed mixed normality across dimensions, requiring both parametric and nonparametric analyses. The lack of normality in two dimensions may reflect heterogeneity of student experiences with scientific ethics and processes—these competencies are more socially constructed and may develop unevenly in culturally diverse groups. This variation reinforces the need to contextualize scientific practices within Indigenous ecological realities.

Table 2.
Normality Test Results (Shapiro-Wilk) for Five Basic Science Literacy Dimensions

Basic Science Literacy Dimension	Pretest p-value	Posttest p-value	Data Distribution	Statistical Test Applied
Conceptual Knowledge	0.082	0.091	Normal	Paired t-test
Scientific Processes	0.012	0.029	Non-Normal	Wilcoxon Signed-Rank Test
Scientific Ethics	0.015	0.036	Non-Normal	Wilcoxon Signed-Rank Test
Attitudes Toward Science	0.065	0.072	Normal	Paired t-test
Scientific Behaviors	0.058	0.061	Normal	Paired t-test

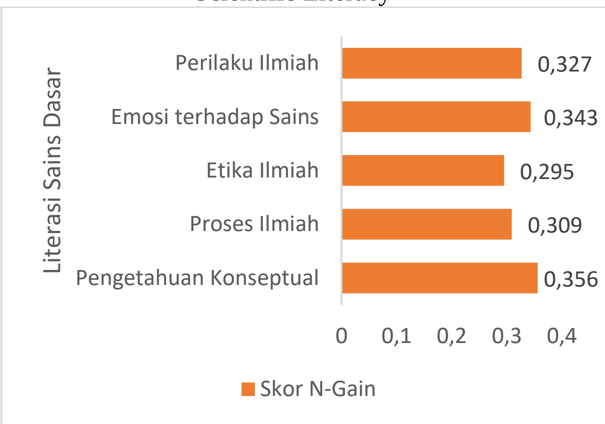
Note. Shapiro–Wilk test was applied to check normality. p > 0.05 indicates data are normally distributed (Paired t-test applied), while p < 0.05 indicates data are non-normally distributed (Wilcoxon Signed-Rank Test applied).

Inferential Analysis

1) N-Gain Scores and Learning Effectiveness

Although the N-Gain values (0.31–0.36) fall within Hake's (1999) moderate category, they still indicate meaningful improvement, considering (a) the short intervention period and (b) students' initial unfamiliarity with inquiry-based learning. The gains also suggest that integrating sago-based investigations helped students internalize science concepts in personally relevant ways, confirming the importance of culturally grounded learning environments. However, the moderate gain also signals that deeper and longer-term integration is required to yield more substantial literacy development.

Figure 1.
N-Gain Scores across Five Dimensions of Basic Scientific Literacy



2) Statistical Significance of Pretest-Posttest Differences

The statistically significant improvements across all dimensions (p < .001; Table 4) indicate that the intervention produced real and measurable effects. Effect sizes ranging from 0.32 to 0.40 fall within a small-to-moderate range (Cohen et al., 2002), which is typical in classroom-based interventions involving marginalized communities with limited prior exposure to scientific inquiry. This reinforces the model's promise but also highlights the necessity of continued research to examine potential cumulative impacts across years of learning rather than a short intervention period.

Table 3.
Statistical Significance of Pretest–Posttest Differences in Scientific Literacy

Dimension	Test Type	Statistical Value	p-value	Effect Size
Conceptual Knowledge	Paired t-test	t = 12.31	< .001	d = 0.34
Scientific Processes	Wilcoxon Test	z = 7.89	< .001	r = 0.35
Scientific Ethics	Wilcoxon Test	z = 7.42	< .001	r = 0.32
Attitudes Toward Science	Paired t-test	t = 11.56	< .001	d = 0.38
Scientific Behaviors	Paired t-test	t = 10.94	< .001	d = 0.40

3) Effect Size

Effect sizes were calculated to assess intervention impact strength using Cohen's (2002) conventions for interpretation. Cohen's d values ranged from 0.32 to 0.40, indicating small-to-moderate effects. While statistically significant improvements were observed, the magnitude of these changes may reflect the relatively short eight-week intervention and the reality that shifting educational practices grounded in long-standing didactic traditions requires extended exposure and cultural negotiation. Moreover, students were initially unfamiliar with inquiry-based and community-engaged learning, which may have limited immediate gains as they adjusted to more participatory roles and dialogic scientific reasoning. Despite these constraints, the effect sizes demonstrate that the intervention produced meaningful progress and highlight the potential for stronger impacts with longer-term implementation and deeper structural support for culturally responsive approaches.

Effect sizes were calculated to assess the strength of the intervention's impact following Cohen's (2002) conventions. The resulting values, ranging from 0.32 to 0.40, fall within the small-to-moderate category, which is typical for classroom-based interventions in marginalized or underserved educational settings. While the improvements achieved were statistically significant, the magnitude of these changes reflects several structural and contextual realities inherent in the learning environment.

One important factor contributing to the moderate nature of the gains is the relatively short duration of the intervention, which spanned only eight weeks. Developing scientific literacy—especially in communities with limited prior exposure to inquiry-oriented pedagogies—requires extended, iterative cycles of practice, reflection, and cultural integration. Short-term interventions may improve foundational understanding, but deeper conceptual restructuring and long-term behavioral changes typically emerge only through sustained engagement.

Additionally, the findings must be interpreted within the broader educational and sociocultural context of the RI–PNG border region. Students participating in this study have long been accustomed to didactic, teacher-centered instruction. The transition toward inquiry-based and community-engaged learning represents a significant paradigm shift, requiring not only new cognitive skills but also changes in classroom norms, communication patterns, and student roles. Such shifts naturally progress gradually, as learners negotiate unfamiliar expectations and gain confidence in dialogic scientific reasoning.

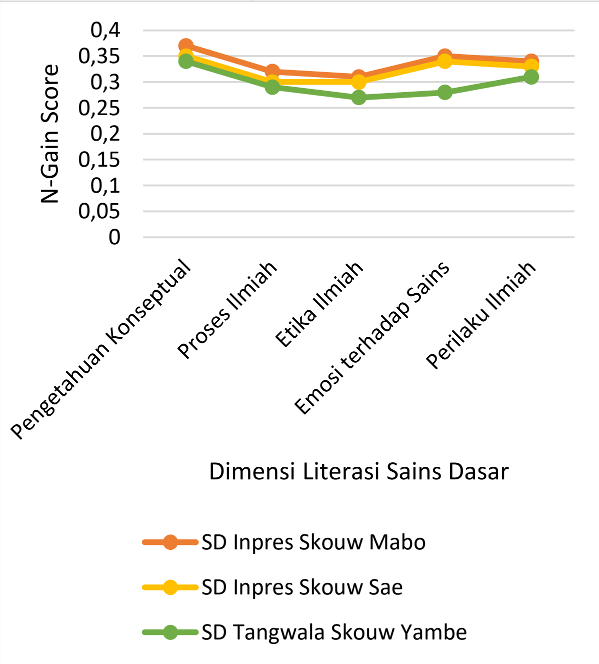
Moreover, the integration of Indigenous ecological knowledge into formal science instruction introduces an additional layer of epistemic negotiation. For many students, connecting traditional ecological practices with scientific principles demands a restructuring of how knowledge is categorized, validated, and communicated. This epistemological reconciliation cannot be rushed, and moderate gains reflect the early stages of this complex process.

Taken together, these factors provide a compelling explanation for why the intervention produced "modest yet meaningful gains." The results demonstrate genuine progress while also highlighting that transformative change in marginalized communities is an incremental process shaped by duration, pedagogical transitions, and the deep-rooted nature of educational traditions. Importantly, the moderate effect sizes underscore the promising potential for larger impacts when culturally responsive and community-based pedagogies are implemented consistently over longer periods and supported through sustained institutional commitment.

4) School-Level Analysis

The slightly lower N-Gain scores in one school—especially in ethics and attitudes—suggest variability in teacher facilitation or community engagement. This aligns with the literature indicating that CRT success relies heavily on consistent educator–community partnerships (Ballard et al., 2023). Such differences emphasize that implementation quality, teacher readiness, and cultural collaboration are critical determinants of educational equity in Indigenous schools.

Figure 2.
N-Gain Scores across Scientific Literacy Dimensions by School



Note. Schools included were SD Inpres Skouw Mabo, SD Inpres Skouw Sae, and SD Tangwala Skouw Yambe. N-Gain interpreted based on Hake's (1998) classification: $g < 0.3$ = low, $0.3 \leq g < 0.7$ = moderate, $g \geq 0.7$ = high.

Qualitative Findings

Qualitative analysis revealed four core learning shifts: (1) strengthening connections between science and culture, (2) improved ecological awareness, (3) utilization of community as a living learning resource, and (4) deeper student reflection (Miles et al., 2014). These shifts demonstrate that the intervention meaningfully supported epistemic engagement, not merely cognitive attainment. Still, some students showed initial hesitation in questioning elders—indicating that transitioning from traditional authority structures to dialogic inquiry requires time and sensitivity to cultural norms.

Teachers reported significant increases in student inquiry behaviors: they asked more "why" and "how" questions related to sago cultivation, indicating cognitive curiosity previously suppressed by passive instruction. Yet, teachers also noted challenges in guiding students from everyday explanations toward more formal scientific reasoning, reflecting the need for sustained professional development to mediate cultural knowledge and school science effectively.

Students' engagement was notably high during outdoor investigations. Their statements illustrated increased agency and ownership of learning. However, analysis of journals suggested variation in depth of reflection—while some students linked sago observations to ecological principles, others remained descriptive. This highlights opportunities to strengthen argumentation scaffolding in future cycles of instruction.

Indigenous elders contributed substantially by demonstrating traditional knowledge and highlighting environmental ethics involved in sago harvesting. Their participation encouraged cultural pride, though logistical constraints limited their classroom involvement during all sessions—suggesting that institutionalized policies are needed to formally embed elders within school structures.

Students' artifacts showed growing ability to express scientific thinking through localized symbolic representations. These products confirmed social relevance and contextual grounding of science, but also revealed ongoing development in abstract reasoning skills.

Traditional sago transplantation practices exemplified how community knowledge embodies scientific principles, affirming Bang et al. (2013) and Ramos (2022). Yet, students initially struggled to articulate connections between these practices and broader ecological theories, indicating that epistemic translation between Indigenous science and school science requires deliberate facilitation.

Collectively, these findings show that culturally grounded learning not only enhances engagement but also supports ecological sustainability values. However, the transferability of such ethical practices beyond sago contexts remains an area for future examination.

Data Integration: Joint Display Analysis

Quantitative and qualitative data were integrated using joint display techniques developed by (Fetters & Tajima, 2022). The integration matrix reveals strong convergence between N-Gain scores and student learning narratives, particularly in conceptual knowledge and scientific process dimensions, as presented in Table 5. Authentic learning experiences prompted active student participation in observations, experiments, and group discussions. This interconnection demonstrates that Indigenous community-based learning enhances both academic outcomes and the development of reflective, contextually grounded scientific thinking.

Table 4.
Quantitative-Qualitative Data Integration on Science Literacy

Dimension	**N-Gain**	**Reflective Quotes**	**Integrated Interpretation**
Conceptual Knowledge	0,356	"I learned that transplanting sago shoots helps them grow better."	Local cultivation methods reinforced comprehension of scientific concepts
Scientific Processes	0,309	"We documented the sago shoot transplantation process."	Direct field observations enhanced understanding of scientific processes
Scientific Ethics	0,295	"Young trees need care, as our elders explained."	Indigenous cultural values fostered ethical responsibility
Attitudes Toward Science	0,343	"I'm proud to learn science from our sago forest."	Familiar learning environments strengthened positive attitudes toward science
Scientific Behaviors	0,327	"I wrote an essay about sago as our life source."	Reflective activities promoted sustainable scientific practices

The joint display (Table 5) revealed clear convergence between increased scores and student narratives—particularly in conceptual and process dimensions. This supports Bauer's (2015) assertion that science literacy must integrate cognitive, affective, and sociocultural elements. However, discrepancies in ethical reasoning indicated that internalization of scientific responsibility is complex and deeply tied to cultural identity, echoing Sharifian et al. (2022). Further refinement in assessment strategies is needed to capture these deeper attitudinal and transformative outcomes.

Discussion

This study confirms that local community engagement plays a central role in enriching science education epistemologies, especially within border regions and Indigenous communities. Consistent with the Funds of Knowledge framework by Moll et al. (2006), the Skouw community maintains sophisticated ecological knowledge and cultural values that remain underutilized in national curriculum development. Context-specific knowledge such as sago fermentation and transplantation practices is both scientifically valid and practically applicable for solving local problems (Anderson, 2024). The findings reinforce that community-based learning creates opportunities for cognitive and cultural reconciliation in science education.

From a critical pedagogical perspective, this initiative aligns with Freire's (1970) view that meaningful education must be dialogical and emancipatory rather than transmissive. By validating local knowledge as a central component of learning, science instruction in the Skouw schools enabled students to recognize themselves as agents of ecological understanding rather than passive receivers of dominant scientific narratives (Nugraha et al., 2024). This pedagogical approach nurtured students' conscientização—critical awareness of the relationships among science, culture, and environmental sustainability—thereby transforming education into a space for collective empowerment in marginalized border contexts.

The constructivist foundations of this study conceptualize learning as socioculturally mediated (Vygotsky & Cole, 1978). Indigenous elders and teachers acted as co-facilitators, supporting students as they investigated biochemical processes in sago fermentation and collaboratively interpreted ecological patterns in the field. This confirms Gay's (2018) argument that culturally responsive teaching enhances motivation by making academic content resonate with learners' lived identities. It also aligns with Kolb's (2014) experiential learning cycle, wherein students applied abstract understanding through direct investigation and evidence-based reflection in culturally meaningful settings.

Crucially, the model operationalized epistemic justice by elevating Indigenous knowledge to equal legitimacy with Western science (Miller & Fox, 2001). Power over knowledge production shifted as elders were invited into curriculum design and instructional delivery, and students' everyday experiences were treated as valid scientific data. This disrupted the hegemony of Western science—which often positions local knowledges as folklore—by establishing a dialogic exchange where scientific principles were understood through Indigenous ecological practices (Bang & Medin, 2010). Rather than culture serving merely as instructional "context," it became a co-equal epistemological foundation, reshaping classroom authority and broadening what counts as scientific reasoning.

Furthermore, this approach advances inclusive community-driven education emphasized by Ballard et al. (2023), ensuring that elders and parents do not function solely as cultural informants but as co-producers of knowledge and sustainability stewards. Students' improved scores across all five basic science literacy dimensions—conceptual knowledge, scientific processes, scientific ethics, science attitudes, and scientific behaviors—affirm the strength of this model in addressing holistic learning needs (Bauer, 2015). Practices such as restrictions on harvesting young sago plants reflect moral ecology that integrates scientific ethics with community survival (Børsen et al., 2021; Ningrum, 2016).

While the research utilized a small and localized sample, this characteristic serves not only as a limitation but also as an essential contextual strength. As a proof-of-concept deeply situated within Indigenous lived experiences, the model offers a transferable framework that prioritizes cultural specificity rather than standardization—consistent with principles of community-based and qualitative research. These insights contribute meaningfully to policy directions in Indonesia's Merdeka Curriculum and UNESCO's recommendations for culturally relevant science education (UNESCO, 2020), demonstrating how school science can become more equitable through dialoguing local wisdom and scientific knowledge systems (Collet-Sabé & Ball, 2023).

CONCLUSION

This study demonstrates that inquiry-based science learning integrating local cultural practices with active Indigenous community participation, specifically sago cultivation in the context of the RI–PNG border region, effectively enhances basic science literacy among students. Significant improvements across all five dimensions were observed. However, the effect sizes (0.32–0.40) indicate a small-to-moderate influence, suggesting that the intervention provided measurable yet realistic gains

The integration of quantitative and qualitative data reveals that this approach not only strengthens conceptual understanding but also fosters emotional engagement, ethical reflection, and sustainable scientific practices. Local contexts play a crucial role in bridging the epistemological gap between academic science and students' cultural experiences, affirming that Indigenous knowledge and traditions constitute primary, rather than supplementary, resources for relevant, contextual, and equitable science education.

This study has several limitations that warrant consideration. Firstly, the implementation scope was restricted to three elementary schools in the RI–PNG border region, requiring cautious generalization to other disadvantaged frontier regions. Secondly, while the mixed-methods approach enriched understanding, the relatively brief intervention period of one semester proved insufficient for observing long-term transformations in students' science literacy and ecological identity.

Subsequent studies should expand participant demographics and locations, including testing the Model of Engaging Communities Collaboratively (MECC) in urban or non-Indigenous contexts. Furthermore, longitudinal research to track science literacy development and ecological attitudes following multi-year community-based learning implementation is needed. In-depth investigation of critical pedagogy dimensions, particularly their impact on students' social consciousness and ecological actions, is another important avenue for future research.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude for the research funding support from the Directorate of Research, Technology, and Community Service (DRTPM) through their 2025 fiscal year grant program. We would also like to thank the Indigenous communities and local leaders of Skouw Sae, Skouw Mabo, and Skouw Yambe for generously sharing their local wisdom. Our sincere appreciation also goes to the teachers and administrators at the three elementary schools on the (RI-PNG) who participated in this research for their invaluable collaboration throughout the process. This research would not have been possible without the collective contributions of these partners.

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