SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 12, No. 4, (2026), pp. 3492-3503
Open Access. Online & Print

DOI: 10.5281/zenodo.12426409

BRIDGING CULTURE AND SCIENCE: POSITIVE IMPACTS OF CULTURALLY RESPONSIVE PEDAGOGY ON ECOLOGICAL LITERACY AND BELONGING

Aisyah Ali[1]*, Singgih Bektiarso[2], Auldry Fransje Walukow[3], Erlia Narulita[4], Akhmad Kadir[5], Ria Ristiani[6]

[1,6]Department of Elementary School Teacher Education, Faculty of Teacher Training and Education, Universitas Cenderawasih, Jayapura, Papua, Indonesia·
[2,4]Doctoral Program in Natural Science Education, Faculty of Teacher Training and Education, Universitas Jember , Jember, Jawa Timur, Indonesia
[3]Department of Physics Education, Faculty of Teacher Training and Education, Universitas Cenderawasih, Jayapura, Papua, Indonesia
[5]Department of Anthropology, Faculty of Social and Educational Sciences, Universitas Cenderawasih, Jayapura, Papua, Indonesia

Received: **05/12/2025**
Accepted: **30/01/2026**

Corresponding Author: Aisyah Ali (aisyahali@fkip.uncen.ac.id)

ABSTRACT

Educational inequality in Indonesia's 3T regions (frontier, outermost, and underdeveloped) continues to marginalize Indigenous learners, whose ecological knowledge and cultural identities are often excluded from science education. Conventional instruction—disconnected from students lived realities—has led to disengagement and weakened affiliation among pre-service teachers in border contexts. This study examines the impact of a culturally responsive science pedagogy on enhancing ecological literacy and affiliation motivation among pre-service teachers at a border university in Papua. An explanatory sequential mixed methods design was adopted. The quantitative phase involved a pretest–posttest design with 102 students, measuring five dimensions of ecological literacy and affiliation motivation. The qualitative phase explored students' experiences through interviews, reflective essays, and classroom artifacts. Findings were integrated using a joint display matrix. Results revealed statistically significant gains across all measured dimensions ($p < 0.001$), with the highest N-Gain scores in ecological behavior (0.375), emotional engagement (0.362), and affiliation motivation (0.360). Thematic analysis showed that students internalized scientific concepts through local ecological practices, developed stronger cultural identities, and began acting as environmental stewards and knowledge mediators. This study highlights the transformative potential of culturally responsive, place-based pedagogy to foster dual literacy—scientific understanding and cultural rootedness—in multicultural teacher education. The findings offer theoretical grounding for reimagining science education in Indigenous contexts and call for the systemic integration of culturally anchored approaches in teacher preparation programs to promote inclusive, sustainable learning in underserved regions.

KEYWORDS: Belonging; Culture; Ecological Literacy; Positive Impacts; Responsive Pedagogy; Science.

1. INTRODUCTION

Addressing educational equity in multicultural and geographically isolated regions is one of the most pressing challenges for teacher education in the Global South (Vo et al., 2022). In Indonesia, the Eastern region—particularly the border areas of Papua—presents a unique socio-educational landscape marked by cultural richness, environmental vulnerability, and systemic marginalization. In this context, pre-service teacher education plays a critical role in cultivating both ecological awareness and social resilience among students. However, current pedagogical models often fail to integrate local cultural practices and social dynamics that shape students' identities, motivations, and learning trajectories.

At the Department of Primary School Teacher Education (PGSD), Faculty of Teacher Training and Education (FKIP), Universitas Cenderawasih, approximately 74% of students come from Indonesia's frontier, outermost, and disadvantaged (3T) areas (Krebs et al., 2021). These students often struggle with structural inequalities such as limited access to quality schooling, digital illiteracy, and cultural dislocation, which not only impede academic achievement but also erode self-confidence and social motivation. In contrast, students from urban or non-3T areas tend to exhibit greater academic self-efficacy but often lack cultural empathy, exacerbating social fragmentation in learning environments (Kauppi et al., 2020). The resulting socio-cultural asymmetry can hinder peer affiliation and undermine the inclusive ethos of teacher education.

One of the key psychosocial dimensions affected by such asymmetry is affiliation motivation, which refers to the desire to build positive relationships within one's learning community (Close & Kelbel, 2019). Low affiliation motivation among 3T students is linked to feelings of inferiority and cultural marginalization, particularly in educational settings that emphasize dominant cultural norms. At the same time, the absence of culturally responsive pedagogies limits the capacity of higher education to affirm local identity and foster deep ecological awareness—skills crucial for future primary educators operating in rural and border contexts.

In this regard, culturally responsive pedagogy (CRP) and place-based education (PBE) offer compelling frameworks for reconfiguring science and environmental education in teacher preparation programs (Bortoleto et al., 2019). CRP emphasizes the alignment of teaching practices with students' cultural knowledge and lived experiences (Kilday & Ryan, 2023), while PBE situates learning within the ecological and cultural context of the community (Sengupta & Guchhait, 2024). Empirical studies demonstrate that these approaches not only enhance conceptual learning, but also strengthen students' affective and ethical engagement with science and society. However, despite their theoretical appeal, such models are rarely implemented in Indonesian border education or systematically evaluated for their impact on ecological literacy and affiliation motivation.

Drawing on Social Identity Theory, this study posits that students develop a sense of belonging and affiliation when their cultural identities are recognized and validated within the learning process (Park et al., 2023). Embedding indigenous ecological knowledge—such as traditional sago cultivation and forest preservation customs—into the science curriculum may serve as a powerful pedagogical strategy for enhancing both ecological literacy and affiliation motivation, particularly among students from marginalized backgrounds (Tiwari & Chowdhary, 2024). Ecological literacy here is understood not merely as scientific knowledge, but as a multidimensional construct involving conceptual understanding, ethical reasoning, emotional engagement, and pro-environmental behavior.

Nevertheless, the existing literature reveals three critical gaps. First, few studies in Indonesia adopt explanatory sequential mixed methods to assess both the effectiveness and meaning of culturally grounded interventions. Second, most CRP implementations remain superficial, often limited to symbolic inclusion of cultural content without meaningful community engagement. Third, there is limited empirical evidence on how indigenous ecological practices can systematically foster both scientific literacy and social motivation among pre-service teachers in marginalized regions.

To address these gaps, this study aims to (1) evaluate the effectiveness of a culturally responsive pedagogy in enhancing ecological literacy and affiliation motivation among PGSD students; (2) explore how the integration of local ecological practices influences students' learning experiences; and (3) offer theoretical and practical insights for developing culturally sustainable science education models in border regions.

By employing an explanatory sequential design, this study not only assesses the quantitative gains in students' learning outcomes but also captures the lived narratives and cultural meanings that shape those outcomes. The findings are expected to contribute to the global discourse on educational

equity, sustainability, and cultural justice in science education.

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 Ecological Literacy in Science Education

Ecological literacy has emerged as a critical educational objective in the 21st century, particularly within the domains of science and environmental education. Coined by Hottenrott & Lawson (2022) and later elaborated by Lopez & Weaver (2023), ecological literacy refers not only to an individual's understanding of natural systems but also to the ethical and behavioral competencies required to live sustainably. In the context of education, ecological literacy includes the ability to think critically about environmental issues, apply scientific reasoning, and act responsibly based on both empirical evidence and local cultural values.

Recent research highlights the inadequacy of decontextualized science instruction in cultivating ecological awareness, especially among students from Indigenous and marginalized communities (Strukova & Polivanova, 2024). When science education is divorced from students lived environments and traditional ecological knowledge (TEK), learners are often alienated from the content and disengaged from the learning process. In contrast, community-based ecological education rooted in local cultural practices has shown promise in enhancing students' conceptual, affective, and behavioral engagement with environmental science.

In border regions such as Papua, traditional practices such as sago cultivation and forest management are not merely agricultural activities—they embody ecological knowledge systems that reflect sustainable land stewardship. These practices can serve as entry points for science learning that is meaningful, culturally affirming, and ethically grounded (Oderich & Baldi, 2020). Therefore, fostering ecological literacy in such contexts necessitates pedagogical models that recognize and integrate local epistemologies.

2.2 Affiliation Motivation and Social Identity in Learning Environments

Affiliation motivation refers to the intrinsic desire to build social connections and positive relationships within one's learning environment (Hautala-Hirvioja, 2022). In higher education, this motivational construct is crucial for fostering engagement, persistence, and academic achievement—especially among students from underrepresented backgrounds (Thako & Waters, 2023). However, students from disadvantaged or culturally distinct communities often experience low levels of affiliation motivation due to systemic exclusion, linguistic barriers, or cultural misrecognition.

To understand how affiliation motivation is shaped in multicultural learning environments, this study draws on Social Identity Theory (SIT), originally developed by Wang (2022). SIT posits that individuals derive part of their self-concept from their membership in social groups, and that perceived group status influences one's sense of belonging and engagement. In educational settings, students whose cultural identities are marginalized may feel devalued, resulting in reduced motivation to affiliate with their peers or institutions.

Studies in culturally diverse classrooms have shown that recognizing students' heritage and promoting inclusive group norms can enhance affiliation motivation and reduce intergroup anxiety (Moralez et al., 2020). Therefore, pedagogical strategies that incorporate students' cultural backgrounds not only support academic learning but also promote social integration and psychological well-being. In this research, affiliation motivation is explored in conjunction with ecological literacy as dual outcomes of culturally grounded pedagogy.

2.3 Culturally Responsive Pedagogy and Place-Based Education

Culturally Responsive Pedagogy (CRP) provides a theoretical and practical foundation for addressing cultural diversity in education (Sutton, 2024). Originally conceptualized by Datsyshen (2022), CRP seeks to align teaching methods, curriculum content, and learning environments with the cultural experiences and knowledge of students. It challenges deficit views of minority students and advocates for asset-based approaches that validate and leverage local cultural practices.

CRP has gained traction in science education for its capacity to contextualize abstract scientific concepts within students' real-life experiences (Paulgaard & Soleim, 2023). When coupled with Place-Based Education (PBE), which emphasizes learning that is situated in the local environment and community (Gruenewald & Smith, 2008), CRP becomes a powerful tool for ecological education. Such integrative models have been shown to improve science outcomes, increase student motivation, and strengthen the relevance of education in marginalized communities.

However, critiques of CRP emphasize that its implementation often remains symbolic—limited to superficial inclusion of cultural content without

structural changes in pedagogy or community engagement. This study addresses these limitations by operationalizing CRP through authentic partnerships with local community members and the integration of traditional ecological practices into inquiry-based science instruction.

2.4 Theoretical Synthesis and Conceptual Model

Building upon the above perspectives, this study is grounded in an integrative theoretical framework that connects ecological literacy, affiliation motivation, and culturally responsive pedagogy (Ryazantsev & Garibova, 2021). The framework posits that when science education:

- draws upon students' cultural identities (via SIT);
- integrates indigenous ecological knowledge (via PBE); and
- engages students through responsive and inquiry-based learning models (via CRP), then both ecological literacy and affiliation motivation can be enhanced synergistically.

This conceptual alignment supports the development of a pedagogical model that is not only culturally relevant and ecologically grounded, but also socially empowering. The study evaluates this model using an explanatory sequential mixed methods approach, allowing for both empirical assessment and qualitative understanding of students' experiences.

3. METHODS

3.1 Research Design

This study employed an explanatory sequential mixed methods design (Mangel, 2006), combining quantitative and qualitative data collection and analysis in two consecutive phases. The first phase involved measuring the changes in students' ecological literacy and affiliation motivation through a pretest–posttest design. The second phase explored students lived experiences and meaning-making through interviews and reflective writings to deepen the interpretation of the quantitative results.

This design was chosen to address the complexity of the research problem, which involves both measurable learning outcomes and context-sensitive cultural dynamics. Integrating both data types enabled the development of a more holistic understanding of how culturally responsive pedagogy affects students' cognitive and affective dimensions of learning.

3.2 Research Setting and Participants

The study was conducted at the Primary School Teacher Education (PGSD) Department, Faculty of Teacher Training and Education (FKIP), Universitas Cenderawasih, Papua, Indonesia (Hancock et al., 2018). The setting was selected purposively due to its sociocultural diversity: approximately 74% of students are from 3T regions, and the remainder from urban, non-3T backgrounds. This composition allowed for the investigation of affiliation dynamics and cultural integration in a heterogeneous academic community.

Participants in the quantitative phase consisted of 102 PGSD students in their second and third year of study, selected through total sampling. All participants completed both the pretest and posttest questionnaires. The qualitative phase involved 16 students (10 from 3T regions and 6 from non-3T), who were selected using maximum variation sampling to capture a wide range of cultural and learning experiences. These students also participated in reflective writing assignments and semi-structured interviews.

3.3 Intervention: Culturally Responsive Science Module

The intervention was a six-week culturally responsive science module developed collaboratively with lecturers and local community members. The module integrated topics such as ecosystem sustainability, biodiversity, and climate adaptation, contextualized through local practices (e.g., sago cultivation, forest conservation rituals, water reuse from traditional fermentation). The instructional design combined inquiry-based learning with cultural narratives, and included outdoor learning activities facilitated by cultural elders (Gray et al., 2007).

Key components included:

- pre-instructional phase: exploration of local ecological issues and cultural beliefs;
- inquiry phase: problem-solving based on real-world practices (e.g., soil and water analysis in sago fields);
- reflection phase: connection of cultural experiences with scientific reasoning and ecological ethics.

The learning process was scaffolded using discussion forums, group reflections, and poster-making to reinforce ecological reasoning and social interaction.

3.4 Instruments and Measures

Ecological literacy was measured using an instrument adapted from McMahon & McGannon (2024), comprising five dimensions: conceptual knowledge, scientific process understanding, ethical reasoning, emotional engagement, and ecological

behavior. Each dimension consisted of four items rated on a 4-point Likert scale (1 = strongly disagree to 4 = strongly agree). The instrument underwent expert validation by science education specialists and demonstrated strong internal consistency (Cronbach's α = 0.81). Affiliation motivation was assessed using a scale developed from the Affiliation Motivation Inventory (Hammersley, 2003), contextualized for multicultural higher education. This scale measured four aspects: desire to collaborate with peers, comfort in classroom interactions, sense of belonging in learning groups, and identification with the academic community. It employed the same 4-point Likert scale and yielded a Cronbach's α of 0.84 following expert validation and pilot testing.

3.5 Data Collection Procedures

The quantitative phase involved a pretest administered prior to the intervention and a posttest conducted upon completion of the culturally responsive science module. Data collection was carried out in supervised classroom settings using both online and paper-based formats. In the subsequent qualitative phase, all participants submitted reflective essays at the end of the intervention, guided by prompts addressing their learning experiences, cultural relevance, and social interactions. Additionally, semi-structured interviews were conducted with 16 selected students, each lasting 30 to 45 minutes, to explore perceptions of personal transformation, cultural resonance, and group dynamics. To ensure data triangulation and contextual richness, classroom observations were conducted and student-generated artifacts—such as group posters and reflective journal entries—were also collected and analyzed.

3.6 Data Analysis

Quantitative data were analyzed using SPSS version 26. Descriptive statistics, including means and standard deviations, were calculated to summarize pre- and post-intervention scores. Data normality was assessed using the Shapiro–Wilk test. For normally distributed variables, paired-sample t-tests were employed, while the Wilcoxon signed-rank test was applied to non-normal data. The effectiveness of the intervention was further examined using normalized gain (N-Gain) scores as outlined by Borcsa & Rober (2015), and practical significance was evaluated using effect size calculations (Cohen's d or rank-biserial r). Qualitative data were analyzed thematically following Gibton's (2015) framework, involving open coding to identify meaningful units, axial coding to develop interpretive categories such as identity, belonging, and ecological reasoning, and selective coding to synthesize overarching narratives across participants. NVivo 15 was used to manage qualitative data through systematic coding, memoing, and theme construction. To integrate both data strands, a joint display matrix was employed, aligning quantitative scores with reflective excerpts to identify patterns of convergence, expansion, and divergence between the two data sources.

4. RESULTS

4.1 Quantitative Findings

The quantitative phase assessed changes in students' ecological literacy and affiliation motivation after completing a six-week culturally responsive science module. A total of 102 students completed both pre- and post-tests.

4.1.1 Descriptive Statistics and Normality Test

Descriptive analysis showed a consistent increase across all dimensions. The most notable gains occurred in ecological behavior, emotional engagement, and affiliation motivation.

Dimension	Pretest Mean (SD)	Posttest Mean (SD)	Mean Increase
Conceptual Knowledge	2.68 (0.53)	3.35 (0.45)	+0.67
Scientific Process	2.57 (0.60)	3.23 (0.48)	+0.66
Ethical Reasoning	2.71 (0.58)	3.28 (0.51)	+0.57
Emotional Engagement	2.59 (0.64)	3.30 (0.55)	+0.71
Ecological Behavior	2.63 (0.57)	3.37 (0.47)	+0.74
Affiliation Motivation	2.55 (0.61)	3.25 (0.52)	+0.70

The Shapiro–Wilk test revealed that data for conceptual knowledge ($p = 0.089$), emotional engagement ($p = 0.076$), and ecological behavior ($p = 0.081$) followed a normal distribution. However, scientific process ($p = 0.021$) and ethical reasoning ($p = 0.032$) did not meet the assumption of normality, necessitating non-parametric analysis for those dimensions.

4.1.2 Inferential Statistics and Instructional Effectiveness

Statistical tests confirmed that all observed gains were significant at $p < 0.001$. Parametric tests (paired t-test) were used for normally distributed data, while the Wilcoxon signed-rank test was applied for non-normal data.

The effectiveness of the intervention was further measured using N-Gain scores. According to Hake (1999), an N-Gain above 0.3 indicates a moderate to high level of effectiveness. This benchmark was met across all dimensions.

Dimension	N-Gain	Effect Size (Cohen's d / r)	Effectiveness Level
Ecological Behavior	0.375	d = 0.92	High
Emotional Engagement	0.362	d = 0.88	High
Affiliation Motivation	0.360	d = 0.84	High
Conceptual Knowledge	0.355	d = 0.81	Moderate–High
Scientific Process	0.334	r = 0.72	Moderate–High
Ethical Reasoning	0.310	r = 0.69	Moderate

These results suggest that the culturally responsive pedagogy produced substantial cognitive and affective gains, especially in dimensions involving real-world behavior and emotional connection.

4.2 Qualitative Findings

To explain the statistical improvements, qualitative data from 16 students were analyzed. Data included reflective essays, interviews, and student-created learning artifacts.

4.2.1 Emergent Themes

Three dominant themes emerged from the thematic analysis:

1. Cultural Anchoring of Scientific Meaning
   Students recognized scientific phenomena in cultural practices such as sago fermentation or forest preservation.

"I never thought fermenting sago was science; now I see the change in smell and color is a real chemical process."

2. Strengthened Sense of Belonging
   Students from 3T areas reported increased confidence and peer interaction.

"I felt proud when we learned using our culture. It made me more confident to speak and join my group."

3. Formation of Ecological Identity
   Several students described behavior change rooted in cultural and ecological ethics.

"I told my family not to cut young sago trees. It's not just tradition—it's about protecting nature."

These qualitative findings demonstrate the transformative impact of culturally embedded learning on both knowledge construction and social motivation.

4.3 Joint Display Integration

To integrate the findings from both phases, a joint display matrix was constructed. This matrix illustrates convergence between N-Gain data and representative student reflections, confirming both statistical and experiential alignment.

The matrix confirms that the pedagogy fostered not only conceptual growth but also identity formation and interpersonal trust. Students did not merely learn about environmental issues; they embedded environmental and social responsibility into their worldview—a core goal of both ecological literacy and social identity-based learning.

Dimension	N-Gain	Illustrative Student Quote
Conceptual Knowledge	0.355	"I realized fermentation in sago is part of science—not separate from real knowledge."
Scientific Process	0.334	"We observed sago leaf decay and saw patterns—like scientists."
Ethical Reasoning	0.310	"I reminded my family not to cut small trees. It's not just adat—it's about care."
Emotional Engagement	0.362	"I was excited when elders joined and shared forest stories—it made learning fun."
Ecological Behavior	0.375	"We made a poster about saving our sago forest—it felt important and real."
Affiliation Motivation	0.360	"Now I talk more with friends from other regions—we share stories, not just tasks."

5. DISCUSSION

This study examined how a culturally responsive science pedagogy affects the development of ecological literacy and affiliation motivation among pre-service teachers in a border education context (Y. Wang et al., 2024). The integration of community-based ecological knowledge—particularly through practices such as sago cultivation and forest conservation—into an inquiry-based science module demonstrated significant learning gains across cognitive, affective, and behavioral domains.

5.1 Pedagogical Relevance of Local Ecological Knowledge

The integration of local ecological knowledge (LEK) into science education has been increasingly recognized as a pedagogical strategy that enhances both the relevance and efficacy of learning, particularly in culturally diverse and ecologically rich communities (Churchill et al., 2024). In this study, the incorporation of traditional sago cultivation, forest conservation practices, and community-enforced ecological ethics into a science module yielded substantial improvements in students' ecological literacy. The data revealed not only cognitive gains in conceptual understanding and scientific process, but also significant affective shifts, as evidenced by increased emotional engagement and environmentally responsible behavior. These outcomes reaffirm the position that pedagogical approaches grounded in community knowledge can serve as powerful levers for

educational transformation in marginalized and remote regions.

Local ecological knowledge, as observed in the traditional practices of Indigenous communities in Papua, offers a unique epistemological lens through which scientific concepts can be contextualized and internalized (Koyama & Watanabe, 2023). Practices such as the prohibition of cutting young sago trees, the fermentation of sago starch, and the spatial management of sago groves are not merely cultural artifacts; they encode empirical understanding of ecosystem dynamics, biological processes, and sustainable resource use. When such practices are positioned as legitimate sources of knowledge in the classroom, they create epistemic bridges between students lived experiences and the formal science curriculum. This not only facilitates deeper conceptual comprehension but also affirms the cultural identities of learners.

The pedagogical effectiveness of integrating LEK is further demonstrated by the high N-Gain scores in the dimensions of ecological behavior (0.375) and emotional engagement (0.362). These scores suggest that students did not merely acquire information, but began to reorient their attitudes and actions in relation to the environment (Gaspar et al., 2024). For example, several participants reported modifying their household behaviors—such as advising family members to reuse sago wastewater or delay cutting sago trees—as a result of insights gained during the learning process. This kind of behavioral transformation aligns with the broader goals of ecological literacy, which extend beyond knowledge acquisition to include ethical reasoning and sustainable action.

Importantly, the pedagogical model used in this study positioned local ecological practices not as anecdotal supplements, but as central themes within an inquiry-based learning framework. This stands in contrast to many conventional approaches where local culture is tokenized or relegated to side discussions. Here, community practices served as entry points for scientific questioning, data gathering, hypothesis testing, and environmental problem-solving. The result was a learning experience that was both intellectually rigorous and culturally affirming, fostering what Zhan (2023) describe as "situated scientific consciousness"—a synthesis of empirical logic and cultural meaning grounded in place.

This pedagogical positioning of LEK also challenges the dominance of Western-centric science instruction that often marginalizes or dismisses Indigenous epistemologies as unscientific or irrelevant. By incorporating the voices and expertise of community elders, students were exposed to alternative ways of knowing that are equally systematic and evidence-based, albeit rooted in oral tradition and embodied practice (Liu & Wu, 2024). This dialogical approach aligns with the decolonizing imperative in science education, which seeks to recognize and legitimize multiple knowledge systems in the construction of scientific understanding. In doing so, the learning process becomes more democratic, inclusive, and socially just.

Ultimately, the relevance of local ecological knowledge in this pedagogical context is twofold: it enhances students' cognitive and affective engagement with science content, and it fosters a sense of ecological identity that is rooted in cultural heritage (Seddighi & Corneliussen, 2025). Students come to see themselves not only as learners of science, but as stewards of their environment and inheritors of ancestral knowledge. This dual positioning—scientific and cultural—equips them with the epistemic agency to navigate both academic and community spheres. As such, the findings from this study support the call for pedagogical models that are culturally embedded, environmentally conscious, and socially transformative—particularly in borderland and 3T educational settings where mainstream curricula often fail to resonate with learners' realities.

5.2 Cultural Validation and Social Identity Formation

The significant improvement in students' affiliation motivation following the culturally responsive science module suggests that validation of cultural identity plays a critical role in fostering psychosocial engagement in academic settings. Affiliation motivation—defined as an individual's intrinsic drive to connect, belong, and participate within a social group (Sherwood et al., 2024) —is particularly salient in multicultural and asymmetrical learning environments such as the PGSD FKIP Universitas Cenderawasih, where students from 3T regions often enter with heightened vulnerability to social exclusion. When instructional content affirms their background, values, and experiences, students demonstrate greater confidence, openness, and willingness to collaborate across sociocultural boundaries.

This study's findings align with the core tenets of Social Identity Theory (SIT) as proposed by Perregaard (2023), which posits that individuals derive part of their self-concept from their

membership in social groups. Students from marginalized communities—whose cultural narratives are frequently absent from dominant curricula—may internalize a sense of inferiority or alienation, thereby weakening their academic engagement and social affiliation. However, when their cultural identity is made visible and valued within the learning environment, the psychological distance between self and institution narrows. In this study, several students from remote areas expressed pride and renewed enthusiasm when their cultural practices became central to classroom inquiry, reflecting a reconfiguration of their perceived social value.

Such cultural validation was not symbolic but experiential. Students did not merely learn about their culture from an outsider's perspective—they became knowledge holders and co-constructors of meaning. By engaging with traditional ecological knowledge through their own familial experiences and community elders, students experienced what Enelamah et al. (2023) describe as "identity-affirming pedagogy," which facilitates academic self-efficacy through the legitimation of one's background as a source of epistemic authority. This shift in positioning—from marginal learner to cultural contributor—appears to have catalyzed higher levels of classroom participation and interpersonal bonding.

The increase in intergroup interaction was particularly notable in student reflections. Participants reported that the learning module prompted cross-regional dialogue among peers, as students from non-3T areas showed curiosity about the traditional practices of their classmates (Aguayo & Eames, 2023). This reciprocal interest not only expanded cultural awareness but also diminished the psychological boundaries that previously marked "in-group" and "out-group" dynamics. This process of mutual recognition supports the idea that culturally responsive pedagogy can function as a social equalizer, disrupting entrenched hierarchies and fostering inclusive communities of practice.

Moreover, the embedded use of storytelling, rituals, and community participation in this module provided students with multiple entry points for emotional and identity resonance. Emotional engagement, as reflected in both qualitative narratives and quantitative scores, appears to be closely intertwined with students' evolving sense of belonging. For many students, science was no longer a foreign or abstract subject, but a lived and shared experience—rooted in their environment, identity, and intergenerational knowledge. This transformation illustrates the pedagogical power of cultural integration not only for cognitive learning, but also for social identity formation and group affiliation.

In conclusion, the observed increase in affiliation motivation among students is not merely a function of content design, but a product of cultural recognition, identity validation, and social inclusion. By creating space for students to engage as both learners and cultural agents, the pedagogy enacted in this study facilitated the emergence of a more cohesive, empathetic, and motivated learning community. These findings underscore the importance of embedding cultural identity into pedagogical design, particularly in regions marked by social disparity and educational marginalization.

5.3 The Role of Culturally Responsive Pedagogy (CRP) in Border Education

Culturally Responsive Pedagogy (CRP) has gained increasing recognition as a strategy for addressing educational inequities in multicultural and underserved communities. In border education contexts—such as the easternmost region of Indonesia where this study was conducted—CRP holds particular promise. These are regions where formal education often overlooks the lived realities of Indigenous populations, resulting in alienation, low engagement, and cultural mismatch between home and school environments (Song & Cutumisu, 2025). The findings of this study demonstrate that CRP, when authentically implemented, can serve not merely as a corrective to curriculum gaps but as a transformative pedagogical framework capable of realigning science education with local knowledge systems and social justice.

One of the key strengths of CRP as operationalized in this study lies in its integration of community participation and local ecological practices into the science learning process. Unlike superficial or tokenistic uses of culture—such as decorative motifs or isolated folklore—the learning module in this study positioned community knowledge as an epistemic foundation for inquiry, observation, and interpretation. Elders served as co-teachers, and cultural practices such as sago fermentation and forest management became focal topics for scientific investigation. This integration made science learning not only more relevant but also more ethical and reciprocal, aligning with Arif et al. (2025) conceptualization of CRP as an education that affirms dignity, agency, and mutual respect.

The borderland nature of the learning context further accentuates the necessity of CRP. Border

regions like Skouw are often liminal spaces where state-sanctioned curricula intersect with multiple languages, histories, and cosmologies. In such spaces, imposing a monolithic, universalized science curriculum risks erasing localized epistemologies and perpetuating colonial educational legacies. The implementation of CRP in this study pushed back against this tendency by embedding scientific reasoning within culturally meaningful contexts—allowing students to see that their everyday experiences and ancestral practices were not antithetical to science, but rather manifestations of it.

Furthermore, the joint display analysis in this study reveals that CRP facilitated not only cognitive learning but also identity development and emotional investment (Nkansah & Oldac, 2024). Dimensions such as ethical reasoning, emotional engagement, and ecological behavior showed moderate-to-high gains, supported by qualitative evidence of students reflecting deeply on their roles as cultural and ecological stewards. These outcomes highlight that CRP, particularly in border education, is not merely a technique for improving academic scores but a framework for nurturing civic consciousness, environmental ethics, and cultural pride—outcomes that conventional pedagogies rarely prioritize.

Despite its potential, the implementation of CRP in border education is not without challenges. It requires educators to shift from being content transmitters to becoming cultural mediators and facilitators of intergenerational knowledge. Institutional constraints such as rigid curricula, lack of localized learning materials, and minimal teacher training on culturally grounded pedagogy often inhibit its adoption (Aguilos et al., 2025). However, the success of the intervention in this study provides an empirical basis to advocate for policy support, institutional investment, and professional development programs that legitimize and scale the use of CRP in remote and Indigenous education settings.

The findings of this study reaffirm the importance of CRP as a transformative educational practice in border regions. By aligning pedagogy with students' cultural contexts and ecological realities, CRP fosters not only scientific literacy but also social inclusion, intergenerational learning, and epistemic justice. For border education systems seeking to empower learners and communities alike, culturally responsive pedagogy offers both a philosophical foundation and a practical roadmap for sustainable, relevant, and inclusive science education.

The outcomes of this study suggest that teacher education programs must go beyond content delivery and actively incorporate students' cultural identities and local ecological contexts (Wei, 2024). In Papua and similar 3T regions, where formal education often marginalizes Indigenous knowledge and environmental realities, culturally responsive pedagogy can:

- enhance the relevance of science learning,
- promote environmental stewardship,
- strengthen intergroup relationships among students, and
- foster community–school partnerships for sustainability.

Additionally, the module used in this study offers a replicable model for developing context-specific curricula that align with both national competencies and local knowledge systems. This is particularly relevant in the era of Merdeka Belajar, where flexible and culturally situated learning is not only encouraged but necessary.

Despite its promising outcomes, this study has several limitations. First, the intervention was conducted over a relatively short period (six weeks), which limits the observation of long-term behavioral change. Second, the qualitative phase involved a small number of participants; although rich in insight, broader generalization must be approached cautiously.

Future research should explore longitudinal designs to assess the sustainability of learning and behavior change. Studies should also investigate how teacher educators themselves perceive and apply CRP in multicultural classrooms, and whether similar interventions are effective in other 3T contexts across Indonesia and Southeast Asia.

6. CONCLUSION

This study provides empirical evidence that culturally responsive pedagogy (CRP), when anchored in Indigenous ecological knowledge and community participation, significantly enhances both ecological literacy and affiliation motivation among pre-service teachers in a border education context. The intervention led to measurable gains across five dimensions of ecological literacy—ranging from conceptual understanding to behavioral engagement—and fostered stronger group affiliation through culturally affirming learning experiences. These findings demonstrate the pedagogical value of integrating local knowledge into science education to foster both cognitive growth and socio-emotional inclusion.

Theoretically, the study contributes to the discourse on social identity in education, confirming that cultural validation enhances students' psychological safety and sense of belonging. Practically, it advocates for the institutional adoption

of CRP in teacher education, particularly in Indonesia's 3T regions, to promote equity, contextual relevance, and sustainability. While acknowledging limitations in duration and scope, the research calls for longitudinal studies and broader implementation to assess the long-term impact and scalability of CRP across diverse educational settings.

7. ACKNOWLEDGMENT

The author would like to express sincere gratitude to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia (Kemendikbudristek) through the Directorate of Research, Technology, and Community Service for the financial support provided under the Fundamental Research Scheme, based on Master Contract No. 065/C3/DT.05.00/PL/2025 dated May 28, 2025, and Subcontract No. 250/UN20.2.1/PG/2025 dated June 4, 2025. This support has significantly contributed to the successful completion of this research.

8. CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

REFERENCES

Aguayo, C., & Eames, C. (2023). Using mixed reality (XR) immersive learning to enhance environmental education. *Journal of Environmental Education*, *54*(1), 58–71. Scopus. https://doi.org/10.1080/00958964.2022.2152410

Aguilos, M., Leggett, Z., Jeffries, S., Lupek, M., & Ardon, M. (2025). University Students' Ecological Footprint and Lifestyle Changes: Awareness vs. Action. *Education Sciences*, *15*(4). Scopus. https://doi.org/10.3390/educsci15040432

Arif, W. P., Sari, M. S., & Lestari, S. R. (2025). Unveiling the roots of botanical literacy: A systematic literature review on its concepts and domains. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(4), 1–12. Scopus. https://doi.org/10.29333/ejmste/16121

Bednarek-Gilland, A. (2015). *Researching values with qualitative methods: Empathy, moral boundaries and the politics of research* (p. 122). Ashgate Publishing Ltd; Scopus. https://www.scopus.com/inward/record.uri?eid=2-s2.0-

Borcsa, M., & Rober, P. (2015). *Research perspectives in couple therapy: Discursive qualitative methods* (p. 176). Springer International Publishing. Scopus. https://doi.org/10.1007/978-3-319-23306-2

Bortoleto, M. A. C., Heinen, T., Jun, S., Toledo, E., Schiavon, L., Pasqua, L., Oliveira, M., & Menegaldo, F. (2019). What motivates people to participate in a non-competitive gymnastics festival? – A case study of world gymnaestrada. *Science of Gymnastics Journal*, *11*(1), 15–22. Scopus.

Churchill, L. R., Henderson, G. E., & King, N. M. P. (2024). Why Climate Literacy Is Health Literacy. *AMA Journal of Ethics*, *26*(2), 147–152. Scopus. https://doi.org/10.1001/amajethics.2024.147

Close, C., & Kelbel, C. (2019). Whose primaries? Grassroots' views on candidate selection procedures. *Acta Politica*, *54*(2), 268–294. Scopus. https://doi.org/10.1057/s41269-018-0086-0

Datsyshen, V. G. (2022). The Chinese Population of Transbaikalia under the Conditions of the Stalinist System in the 1930s. *RUDN Journal of Russian History*, *21*(1), 57–71. Scopus. https://doi.org/10.22363/2312-8674-2022-21-1-57-71

Enelamah, N. V., Lombe, M., Betancourt, T. S., Williams, D. R., & Shen, C. (2023). Variations in risk, resilience, and protective factors for cognitive and socioemotional development among 3- to 4-year-old children in Nigeria: A multilevel modeling. *Early Childhood Research Quarterly*, *64*, 162–173. Scopus. https://doi.org/10.1016/j.ecresq.2023.02.006

Gaspar, T., Carvalho, M., Guedes, F. B., Cerqueira, A., & de Matos, M. G. (2024). Who are the Happy Girls? Gender Comparison Using a Biopsychosocial Approach: Health Behavior School-Aged Children Study in Portugal During Covid-Pandemic. *Child Indicators Research*, *17*(2), 845–868. Scopus. https://doi.org/10.1007/s12187-023-10092-4

Gibton, D. (2015). *Researching education policy, public policy, and policymakers: Qualitative methods and ethical issues* (p. 226). Taylor and Francis; Scopus. https://doi.org/10.4324/9781315775722

Gray, P. S., Williamson, J. B., Karp, D. A., & Dalphin, J. R. (2007). *The research imagination: An introduction to qualitative and quantitative methods* (p. 456). Cambridge University Press. Scopus. https://doi.org/10.1017/CBO9780511819391

Hammersley, M. (2003). *The Dilemma Of Qualitative Method: Herbert Blumer and the Chicago Tradition* (p. 271). Taylor and Francis. Scopus. https://doi.org/10.4324/9780203392904

Hancock, G. R., Stapleton, L. M., & Mueller, R. O. (2018). *The Reviewer's Guide to Quantitative Methods in the Social Sciences: Second Edition* (p. 502). Taylor and Francis. Scopus. https://doi.org/10.4324/9781315755649

Hautala-Hirvioja, T. (2022). The Opportunities for and Limitations on a Finnish Female Artist in Lapland before the Second World War. *Journal of Finnish Studies*, *25*(1), 22–46. Scopus. https://doi.org/10.5406/28315081.25.1.02

Hottenrott, H., & Lawson, C. (2022). What is behind multiple institutional affiliations in academia? *Science and Public Policy*, *49*(3), 382–402. Scopus. https://doi.org/10.1093/scipol/scab086

Kilday, J. E., & Ryan, A. M. (2023). Who Do Students Ask for Help With Classwork? Sources of Help and Changes in Help-Seeking From Peers During Early Adolescence. *Journal of Early Adolescence*, *43*(6), 746–783. Scopus. https://doi.org/10.1177/02724316221124784

Koyama, D., & Watanabe, T. (2023). Why a dispositional view of ecological literacy is needed. *Teaching in Higher Education*, *28*(5), 1108–1117. Scopus. https://doi.org/10.1080/13562517.2023.2198637

Krebs, R. R., Ralston, R., & Rapport, A. (2021). Why They Fight: How Perceived Motivations for Military Service Shape Support for the Use of Force. *International Studies Quarterly*, *65*(4), 1012–1026. Scopus. https://doi.org/10.1093/isq/sqab033

Liu, D., Wang, L., Xu, Z., Li, M., Malatesha Joshi, R., Li, N., & Zhang, X. (2023). Understanding Chinese children's word reading by considering the factors from cognitive, psychological and ecological factors. *Contemporary Educational Psychology*, *73*. Scopus. https://doi.org/10.1016/j.cedpsych.2023.102163

Liu, Q., & Wu, J. (2024). What children learn in a digital home: The complex influence of parental mediation and smartphone interference. *Education and Information Technologies*, *29*(5), 6273–6291. Scopus. https://doi.org/10.1007/s10639-023-12071-2

Lopez, C. W., & Weaver, R. (2023). What influences where volunteers practice environmental stewardship? The role of scale(s) in sorting stewards. *Journal of Environmental Planning and Management*, *66*(9), 1983–2008. Scopus. https://doi.org/10.1080/09640568.2022.2049596

Mangel, M. (2006). *The theoretical biologist's toolbox: Quantitative methods for ecology and evolutionary biology* (p. 375). Cambridge University Press. Scopus. https://doi.org/10.1017/CBO9780511819872

McMahon, J., & McGannon, K. R. (2024). *Trauma-informed research in sport, exercise, and health: Qualitative methods* (p. 268). Taylor and Francis. Scopus. https://doi.org/10.4324/9781003332909

Moralez, E., Thompson, B., Englund, K., Drennan, M., Mandall, N., & Loest, H. (2020). The Health Disparities Field Experience: College students and community health workers in the field. *Journal of Education and Health Promotion*, *9*(1). Scopus. https://doi.org/10.4103/jehp.jehp_510_20

Nkansah, J. O., & Oldac, Y. I. (2024). Unraveling the attributions of digital literacy skills and knowledge gap in Ghana's higher education: Undergraduate students voices in a phenomenological study. *Education and Information Technologies*, *29*(12), 15249–15268. Scopus. https://doi.org/10.1007/s10639-024-12483-8

Oderich, C. L., & Baldi, M. (2020). Transforming the territory: The importance of the Latin American Integration University for culture in the Brazil-Paraguay-Argentina triple frontier. *Revista Brasileira de Educacao*, *25*, 1–17. Scopus. https://doi.org/10.1590/S1413-24782020250059

Park, Y., MacDonald, G., Impett, E. A., & Neel, R. (2023). What Social Lives Do Single People Want? A Person-Centered Approach to Identifying Profiles of Social Motives Among Singles. *Journal of Personality and Social Psychology*, *125*(1), 219–236. Scopus. https://doi.org/10.1037/pspp0000455

Paulgaard, G., & Soleim, M. N. (2023). The arctic migration route: Local consequences of global crises. *Journal of Peace Education*, *20*(2), 196–216. Scopus. https://doi.org/10.1080/17400201.2022.2159794

Perregaard, B. (2023). Voice, rhythm, and genre in children's early writing. *Language Sciences*, *96*. Scopus. https://doi.org/10.1016/j.langsci.2022.101525

Ryazantsev, S., & Garibova, F. (2021). Tajik-afghan border areas as a socio-economic and ethnocultural contact zone. *Central Asia and the Caucasus*, *22*(3), 146–156. Scopus. https://doi.org/10.37178/ca-c.21.3.012

Seddighi, G., & Corneliussen, H. G. (2025). Welfare Service Providers' Narratives of Digital Literacies Among Vulnerable Youths in Norway. *Journal of Applied Youth Studies*, *8*(1), 133–152. Scopus. https://doi.org/10.1007/s43151-024-00147-w

Sengupta, S., & Guchhait, S. K. (2024). While stairing up: Perceiving shades of academic motivation of high school first-generation learners and desired academic outcomes. *Discover Education*, *3*(1). Scopus. https://doi.org/10.1007/s44217-024-00315-3

Sherwood, D., VanDeusen, K., Leahy, A., & Diaconu, M. (2024). "We're an escuelita, a Little School": Unsettling Disaster Relief Work in the Caño Martín Peña Communities of Puerto Rico. *Journal of Community Practice*, *32*(4), 462–485. Scopus. https://doi.org/10.1080/10705422.2024.2428862

Song, Y., & Cutumisu, M. (2025). Using machine learning to predict student science achievement based on science curriculum type in TIMSS 2019. *International Journal of Science Education*, *47*(9), 1105–1149. Scopus. https://doi.org/10.1080/09500693.2024.2359099

Strukova, A. S., & Polivanova, K. N. (2024). What do Parents of Homeschoolers Do to Improve the Well-being of their Children (Based on SDT-approach). *Cultural-Historical Psychology*, *20*(4), 60–67. Scopus. https://doi.org/10.17759/chp.2024200407

Sutton, D. S. (2024). Territorialization and ethnic control in China's borderlands: Aba prefecture in the People's Republic, 1950–2020. *Eurasian Geography and Economics*, *65*(6–7), 753–782. Scopus. https://doi.org/10.1080/15387216.2024.2343659

Thako, H., & Waters, T. (2023). Schooling, Identity, and Nationhood: Karen Mother-Tongue-Based Education in the Thai–Burmese Border Region. *Social Sciences*, *12*(3). Scopus. https://doi.org/10.3390/socsci12030163

Tiwari, P., & Chowdhary, N. (2024). What makes Indian domestic tourists crowd-friendly in the post-COVID-19 phase? *International Journal of Tourism Cities*, *10*(1), 6–22. Scopus. https://doi.org/10.1108/IJTC-04-2022-0089

Vo, T.-T.-D., Tuliao, K.-V., & Chen, C.-W. (2022). Work Motivation: The Roles of Individual Needs and Social Conditions. *Behavioral Sciences*, *12*(2). Scopus. https://doi.org/10.3390/bs12020049

Wang, J. (2022). The Latinxua Sin Wenz Movement in the Shaanxi-Gansu-Ningxia Border Region of China: Centred on Winter schools in Yan'an County. *Cultura. International Journal of Philosophy of Culture and Axiology*, *19*(1), 101–120. Scopus. https://doi.org/10.3726/cul012022.0008

Wang, Y., Zhao, Y., Lu, J., & Gao, Y. (2024). Young Children's Digital Literacy Practices with Caregivers in the Home Environment: Voices of Chinese Parents and Grandparents. *Sustainability (Switzerland)*, *16*(8). Scopus. https://doi.org/10.3390/su16083300

Wei, W. S. (2024). Under what conditions does missing school matter most? Examining associations between absenteeism and child outcomes in Head Start. *Children and Youth Services Review*, *163*. Scopus. https://doi.org/10.1016/j.childyouth.2024.107766

Zhan, Y. (2023). What do college students think of feedback literacy? An ecological interpretation of Hong Kong students' perspectives. *Assessment and Evaluation in Higher Education*, *48*(5), 686–700. Scopus. https://doi.org/10.1080/02602938.2022.2121380