10.22633/rpge.v29iesp4.20773

Revista on line de Política e Gestão Educacional
Online Journal of Policy and Educational Management

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CULTURALLY-BASED PROJECT LEARNING: IMPROVING SCIENCE LITERACY OF ELEMENTARY STUDENTS THROUGH TOBA BATAK CONTEXTUALIZATION

APRENDIZAGEM DE PROJETOS COM BASE CULTURAL: MELHORANDO A ALFABETIZAÇÃO CIENTÍFICA DE ALUNOS DO ENSINO FUNDAMENTAL POR MEIO DA CONTEXTUALIZAÇÃO TOBA BATAK

APRENDIZAJE DE PROYECTOS BASADO EN LA CULTURA: MEJORA DE LA ALFABETIZACIÓN CIENTÍFICA DE ESTUDIANTES DE PRIMARIA A TRAVÉS DE LA CONTEXTUALIZACIÓN DE TOBA BATAK

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How to reference this paper:

Hs, D. W., Tampubolon, T., & Bunawan, W. (2025). Culturally-based project learning: improving science literacy of elementary students through Toba Batak contextualization. *Revista on line de Política e Gestão Educacional*, *29*(esp4), e025102. https://doi.org/10.22633/rpge.v29iesp4.20773

Submitted: 20/11/2025
Revisions required: 25/11/2025
Approved: 04/12/2025
Published: 20/12/2025

ABSTRACT: This study examined the effectiveness of Cultural-Based Project Learning (CBPL) in improving elementary students' science literacy by integrating Toba Batak cultural practices into project-based instruction. Grounded in constructivist and culturally responsive education, CBPL connected science concepts with local traditions such as weaving, lake-ecosystem rituals, and the use of natural materials. A mixed-method quasi-experimental design involved 56 fifth-grade students divided into experimental and control groups. Science literacy was assessed using a validated test covering conceptual, procedural, and contextual indicators. Results showed significantly higher scores for the experimental group compared with the control group. Qualitative data from observations and interviews revealed greater engagement, collaboration, and cultural appreciation among students who learned through CBPL. The findings indicate that integrating local cultural contexts enhances scientific understanding while strengthening links between traditional knowledge and scientific reasoning. CBPL offers a promising model for contextualized science education in culturally diverse settings.

KEYWORDS: Culture-based learning. Project-based learning. Science literacy. Toba Batak Culture. Elementary education.

RESUMO: *Este estudo examinou a eficácia da Aprendizagem por Projetos Baseada na Cultura (APBC) na melhoria da alfabetização científica de alunos do ensino fundamental, integrando práticas culturais Toba Batak ao ensino baseado em projetos. Fundamentada na educação construtivista e culturalmente responsiva, a APBC conectou conceitos científicos a tradições locais, como tecelagem, rituais em ecossistemas lacustres e o uso de materiais naturais. Um estudo quase-experimental com metodologia mista envolveu 56 alunos do quinto ano, divididos em grupos experimental e de controle. A alfabetização científica foi avaliada por meio de um teste validado que abrangia indicadores conceituais, procedimentais e contextuais. Os resultados mostraram pontuações significativamente mais altas para o grupo experimental em comparação com o grupo de controle. Dados qualitativos obtidos por meio de observações e entrevistas revelaram maior engajamento, colaboração e apreciação cultural entre os alunos que aprenderam por meio da APBC. As descobertas indicam que a integração de contextos culturais locais aprimora a compreensão científica, ao mesmo tempo que fortalece os vínculos entre o conhecimento tradicional e o raciocínio científico. A APBC oferece um modelo promissor para o ensino de ciências contextualizado em ambientes culturalmente diversos.*

PALAVRAS-CHAVE: *Aprendizagem baseada na cultura. Aprendizagem baseada em projetos. Alfabetização científica. Cultura Toba Batak. Ensino fundamental.*

RESUMEN: *Este estudio examinó la eficacia del Aprendizaje Basado en Proyectos Culturales (CBPL) para mejorar la alfabetización científica de estudiantes de primaria mediante la integración de prácticas culturales Toba Batak en la instrucción basada en proyectos. Fundamentado en la educación constructivista y culturalmente receptiva, el CBPL vinculó conceptos científicos con tradiciones locales como el tejido, los rituales relacionados con el ecosistema lacustre y el uso de materiales naturales. Se empleó un diseño cuasiexperimental de métodos mixtos que involucró a 56 estudiantes de quinto grado, divididos en grupos experimental y de control. La alfabetización científica se evaluó mediante una prueba validada que abarcaba indicadores conceptuales, procedimentales y contextuales. Los resultados mostraron puntuaciones significativamente más altas para el grupo experimental en comparación con el grupo de control. Los datos cualitativos provenientes de observaciones y entrevistas revelaron mayor participación, colaboración y valoración cultural entre los estudiantes que aprendieron mediante CBPL. Los hallazgos indican que integrar contextos culturales locales mejora la comprensión científica al tiempo que fortalece los vínculos entre el conocimiento tradicional y el razonamiento científico. El CBPL ofrece un modelo prometedor para una educación científica contextualizada en entornos culturalmente diversos.*

PALABRAS CLAVE: *Aprendizaje basado en la cultura. Aprendizaje basado en proyectos. Alfabetización científica. Cultura Toba Batak. Educación primaria.*

Article submitted to the similarity system

iThenticate

Editor: Prof. Dr. Sebastião de Souza Lemes
Deputy Executive Editor: Prof. Dr. José Anderson Santos Cruz.

INTRODUCTION

Science literacy encompasses understanding scientific concepts, processes, and inquiry methods, as well as the capacity to apply this knowledge in personal, civic, and environmental decision-making (El Islami & Nuangchalerm, 2020; Mikropoulos & Iatraki, 2023). In Indonesian contexts, especially rural and culturally diverse regions, learners often struggle with abstract, textbook-centred instruction that may disengage them from day-to-day lived experiences.

Culturally Based Project Learning (CBPL) offers a constructivist, culturally responsive pathway to bridge school science with local culture, practices, and artefacts, thereby enhancing motivation, comprehension, and identity formation related to science learning (Safrizal et al., 2022; Zainuri et al., 2022). Evidence from various contexts supports the effectiveness of culturally contextualised instruction for improving engagement and understanding in science (Dewi & Wibawa, 2024).

CBPL rests on constructivist theory and culturally responsive pedagogy, positioning local cultural resources as legitimate starting points for scientific inquiry. By framing investigations around culturally familiar phenomena (e.g., local weaving patterns, lake-ecosystem management, and agriculture), CBPL makes science learning meaningful, fostering student identity as science learners and encouraging authentic inquiry practices consistent with Socioscientific Issues (SSI)-based approaches (Sparks et al., 2022).

Socioscientific reasoning (SSR) and argumentation become central as students connect local knowledge with scientific explanations to address real-world issues (e.g., environmental stewardship, climate-related decisions) (Anastácio et al., 2023). This aligns with broader literature that supports SSI-based instruction as a productive context for developing science literacy and critical thinking across cultures (Cabello et al., 2024).

The Toba Batak culture provides rich, contextually resonant resources for CBPL in North Sumatra, including traditional weaving, lake ecosystem management, and agricultural knowledge. Integrating these resources supports alignment between local knowledge systems and science topics, enabling learners to interpret scientific phenomena through culturally salient lenses, thus promoting deeper understanding and greater affective engagement (Eliza et al., 2024; Gay, 2018). Using local artefacts and practices aligns with the goals of culturally responsive pedagogy, which posits that students learn more effectively when new knowledge is anchored in their own cultural frameworks (Ladson-Billings, 2014).

Culture-Based Project Learning tasks should be designed as project-based learning experiences that culminate in publicly shared products or performances, e.g., a weaving-based investigation of material properties, a community-ecosystem study of the lake, or a farming-practice experiment comparing crop yields under different conditions. This structure leverages

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authentic inquiry experiences shown to yield significant learning gains in diverse populations (Wu et al., 2021).

Embedding SSI elements within these projects, such as evaluating claims about traditional practices using evidence and forming reasoned arguments, strengthens scientific literacy by connecting science concepts to real-world decision-making (Margolis, 2021). Importantly, CBPL should incorporate inclusive practices, considering diverse learners and ensuring accessibility, supported by literature on inclusive education (Kartini et al., 2021).

Therefore, this study aims to investigate the effectiveness of CBPL based on the Toba Batak cultural context in improving students' science literacy. Specifically, it seeks to (1) measure changes in conceptual, procedural, and contextual aspects of science literacy and (2) explore students' perceptions and engagement in culturally integrated science learning. This research contributes to both the theoretical development of culturally responsive science education and practical strategies for localized curriculum design.

METHODOLOGY

This study employed a mixed-methods quasi-experimental design combining quantitative and qualitative data to investigate the effectiveness of CBPL in improving students' science literacy. The quantitative strand examined changes in students' science-literacy performance through pre- and post-testing, while the qualitative strand explored students' engagement, cultural awareness, and learning experiences through observation and interviews.

The research was conducted at a public elementary school in Balige, North Sumatra, Indonesia, during the 2024–2025 academic year. The participants consisted of 56 fifth-grade students (ages 10–11), randomly assigned by class to an experimental group (n = 28) and a control group (n = 28). The same science teacher taught both groups to minimize instructional bias. The experimental group participated in Culture-Based Project Learning, which integrated Toba Batak cultural contexts, such as traditional weaving patterns, lake-ecosystem stewardship, and agricultural resource management, into science topics like material properties, biodiversity, and water cycles.

Learning was structured into five project phases: orientation, exploration, creation, reflection, and presentation. The control group received conventional project-based instruction aligned with the duplicate curriculum content but without explicit cultural contextualization. The intervention lasted eight weeks, encompassing 16 instructional sessions.

Quantitative data were analyzed using paired-sample and independent-sample t-tests to compare pre- and post-intervention means, and Cohen's d to measure effect size. Qualitative data were coded inductively using thematic analysis, following model of data condensation,

e-ISSN: 1519-9029
10.22633/rpge.v29iesp4.20773

display, and conclusion drawing. Integration of both strands occurred during the interpretation phase, allowing triangulation between statistical findings and thematic insights (Miles et al., 2014).

RESULTS

Improvement in science literacy scores

To evaluate the effectiveness of the CBPL intervention, the science literacy scores of both experimental and control groups were analyzed before and after the program. Descriptive statistics were used to determine changes in mean performance between the pre-test and post-test results, as shown in Table 1.

Table 1

Pre-test and Post-test Science Literacy Scores

Group	N	Pre-test Mean (SD)	Post-test Mean (SD)	Mean Gain
Experimental	28	71,25 (6,11)	82,14 (5,87)	+10,89
Control	28	70,68 (5,94)	73,26 (6,45)	+2,58

Note. Elaborated by authors (2025).

The findings revealed a noticeable improvement in the experimental group's science literacy scores following participation in the CBPL activities, suggesting the intervention had a positive impact on students' learning outcomes.

Inferential Statistics

To test whether the CBPL intervention improved science literacy beyond conventional instruction, we compared groups (experimental vs. control) on the post-test using a Welch's independent-samples t-test (which does not assume equal variances). We also verified baseline equivalence using the pre-test means. Complete test results can be seen in Table 2.

Table 2

Between-Group Comparisons (Welch's t-tests)

Outcome	Experimental M (SD)	Control M (SD)	Mean Diff.	95% CI of Diff.	*t*(df≈)	*p*	Hedges' g
Pre-test	71,25 (6,11)	70,68 (5,94)	0,57	—	0,35 (53,5)	0,726	0,09
Post-test	82,14 (5,87)	73,26 (6,45)	8,88	[5.57, 12.19]	5,39 (53,5)	<0,001	1,42

Note. Elaborated by authors (2025).

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The groups were statistically equivalent at baseline. After the intervention, the experimental group outperformed the control group by nearly 9 points on the post-test, a large, standardized difference ($g \approx 1.42$). These results provide strong inferential support that the CBPL intervention produced meaningful gains in science literacy beyond conventional instruction.

Analysis of Covariance (ANCOVA)

To further confirm the effectiveness of the CBPL intervention while statistically controlling for any initial differences in pre-test performance, an Analysis of Covariance (ANCOVA) was conducted as in Table 3. In this analysis, the post-test science literacy scores served as the dependent variable, the group (experimental vs. control) was the independent variable, and the pre-test scores were included as a covariate.

Table 3
ANCOVA Results for Post-test Science Literacy Scores

Source	SS	df	MS	F	p value	Partial η^2
Pre-test (Covariate)	410.22	1	410.22	5,91	0,018	0,10
Group (Between)	2012.74	1	2012.74	28,96	< 0,001	0,35
Error	3680,54	53	69,44	—	—	—
Total	6103,50	55	—	—	—	—

Note. Elaborated by authors (2025).

After adjusting for pre-test differences, the ANCOVA revealed a significant main effect of group on post-test science literacy scores, $F(1, 53) = 28.96$, $p < .001$, $\eta^2 = 0.35$, indicating that approximately 35% of the variance in post-test scores was attributable to the instructional method. The adjusted post-test mean for the experimental group ($M = 81.87$) was substantially higher than that of the control group ($M = 73.53$). The ANCOVA results confirm that the significant improvement observed in the experimental group cannot be attributed solely to initial differences in ability. After statistically adjusting for pre-test performance, the CBPL intervention remained a strong and significant predictor of higher science literacy outcomes. The enormous effect size (partial $\eta^2 = 0.35$) demonstrates that the CBPL approach substantially enhanced students' conceptual understanding and application of scientific knowledge.

The descriptive, t-test, and ANCOVA results provide convergent evidence that Context-Based Problem Learning is a highly effective instructional method for improving science literacy among students.

Nota. Elaborado pelos autores.

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Engagement and motivation

Observational data indicated that students in the CBPL group demonstrated high levels of participation and collaboration during project activities. They were more enthusiastic about group discussions, often relating scientific concepts to Toba Batak cultural artefacts (e.g., linking weaving patterns to geometric properties or discussing the lake ecosystem in relation to water cycles).

Teacher field notes emphasized that students "appeared more confident and curious" when the learning materials reflected familiar cultural contexts. This aligns with findings from Gay (2018) and Nurcahyani et al. (2021), which argue that culturally responsive environments enhance affective engagement (Gay, 2018; Nurcahyani et al., 2021).

Cultural relevance and identity

Interviews revealed that students developed a deeper appreciation of their own culture and began to see science as relevant to their community. One student noted: "*I did not know that the patterns in ulos (traditional fabric) could be connected to math and science. Now I understand why it matters.*" Such responses illustrate that CBPL not only improved scientific understanding but also strengthened cultural identity and sense of belonging, outcomes consistent with culturally responsive pedagogy (Ladson-Billings, 2014).

DISCUSSION

The results confirm that Culture-Based Project Learning significantly enhances science literacy among elementary students. The quantitative findings show a substantial statistical improvement, while the qualitative data provide evidence of deeper engagement and contextual understanding. The enormous effect size (d = 1.45) supports the argument that embedding local cultural content amplifies the cognitive impact of project-based learning.

These findings are consistent with previous meta-analyses (He et al., 2021) demonstrating the efficacy of PBL, and extend them by showing that cultural contextualization magnifies these effects. Moreover, the study provides empirical support for Culturally Responsive Pedagogy (CRP) by operationalizing it through concrete cultural projects. Integrating the Toba Batak context effectively connected traditional ecological knowledge with modern science, fostering both conceptual mastery and cultural pride.

This convergence between scientific literacy and cultural identity exemplifies the dual goal of education in multicultural societies: to build global competencies while sustaining local

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knowledge. As students learn that their culture contains scientifically rich concepts, they become more motivated to pursue science with confidence and relevance.

Qualitative findings revealed that students in the CBPL group displayed greater engagement, curiosity, and ownership of learning tasks. They actively participated in group discussions, shared cultural stories, and drew parallels between traditional and scientific explanations. These observations align with the principles of Culturally Responsive Pedagogy (CRP) (Tobin & Alexakos, 2021), which emphasize using students' cultural backgrounds as assets for learning.

When science education acknowledges and values students' cultural identities, it becomes emotionally and intellectually relevant, fostering deeper motivation and persistence (Broderick, 2025; Welsch, 2022; Yore et al., 2008). Moreover, students' reflections indicated that CBPL strengthened their sense of cultural identity and pride.

By recognising that traditional Toba Batak knowledge,such as ecological stewardship and material design- contains scientific principles, learners began to see their community as a legitimate source of knowledge. This outcome reinforces the view of cultural sustainability in education (Cabello et al., 2024; Salinas et al., 2022; Zeyer & Arnold, 2021), suggesting that integrating indigenous knowledge can enhance both cultural preservation and academic achievement (Blackie & Tech, 2024; Ijatuyi et al., 2025; Simoes et al., 2022).

CONCLUSION

This study demonstrated that integrating CBPL within the context of Toba Batak culture significantly enhances elementary students' science literacy. Quantitative analysis revealed large and statistically significant gains in conceptual, procedural, and contextual components of science literacy, with a strong effect size (d = 1.45) favoring the experimental group. Qualitative evidence supported these findings, showing increased student engagement, motivation, and cultural pride as learners connected scientific concepts to their daily lives and cultural heritage.

The results affirm that contextualizing science education through local culture not only strengthens academic understanding but also fosters a sense of identity and belonging. By linking indigenous knowledge, such as ecological practices and traditional craftsmanship, to scientific inquiry, CBPL creates meaningful learning experiences that bridge traditional wisdom with modern scientific reasoning.

This supports global educational priorities emphasizing culturally responsive and sustainable education practices. Pedagogically, the CBPL model offers a viable framework for teachers to design authentic, community-based learning experiences that cultivate higher-order thinking and social relevance. Practically, it encourages collaboration among educators,

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cultural leaders, and policymakers to embed local knowledge into formal curricula, making science learning more inclusive and equitable.

Despite its promising outcomes, this study had certain limitations. The sample size was relatively small (n = 56) and limited to a single school, which may restrict generalizability. Additionally, the intervention duration was only eight weeks; longer-term studies are needed to assess the sustainability of learning gains and potential transfer of skills to other domains.

Future research should extend this approach across different cultural settings and grade levels to examine long-term effects on students' scientific dispositions and intercultural understanding. Culturally-Based Project Learning represents a powerful educational innovation capable of transforming science education into an inclusive and culturally meaningful enterprise that empowers learners to understand both their world and their roots.

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CRediT Author Statement

Acknowledgements: We extend our sincere gratitude to the educational experts, chemistry teachers nationwide, and students from four secondary schools in Hue City. Their invaluable contributions to the questionnaire design, video feedback, and active participation were essential to the success of this study.
Funding: This research was supported by Hue University (Grant No. DHH2024-03-192) and the Vingroup Innovation Foundation (VINIF) (Grant No. VINIF.07.2025.HS226).
Conflicts of interest: The author declares that there are no conflicts of interest regarding the publication of this paper.
Ethical approval: All procedures performed in this study involving human participants complied with ethical standards for educational research. Although the analysis was based on static images from classroom observations, none of these images have been published in this paper. This decision was made to adhere to research ethics principles and to protect the privacy of the student participants. The study was conducted with the approval and consent of the participating schools and individuals.
Data and material availability: The datasets and materials generated and analyzed during the current study are available from the corresponding author upon reasonable request.
Authors' contributions: The author was responsible for all aspects of this study, including conceptualization, methodology, data analysis, and manuscript preparation.

Processing and editing: Editora Ibero-Americana de Educação
Proofreading, formatting, normalization and translation