



Integrating Ethnoscience into Eco-Gamified Problem-Based Learning to Improve Sustainability Literacy and Environmental Awareness in Peatlands

Mohamad Nor Aufa^{1*}, Gusti Nida Nurkhaliza¹, Muhammad Hasbie², and Rusmansyah³

¹Biology Education, Muhammadiyah University of Palangka Raya, Palangka Raya, Indonesia

²Elementary Madrasah Teacher Education, STAI Al Falah Banjarbaru, Banjar Baru, Indonesia

³Chemistry Education, Faculty of Teacher Training and Education, Banjarmasin, Indonesia

*mohamadnoraufa16@gmail.com

Article Info	Abstract
Article history: Received: March 2, 2026 Accepted: April 20, 2026 Published: May 24, 2026	This study aims to analyze the effect of implementing the ethnoscience-based Eco-Gamified Problem-Based Learning (PBL) model within peatland contexts on the sustainability literacy and environmental awareness of junior high school students. A quasi-experimental design with a non-equivalent control group was employed, involving 65 students (32 in the experimental group and 33 in the control group). The experimental group received the Eco-Gamified PBL intervention integrating peatland ethnoscience, while the control group received conventional instruction. Data were collected through a sustainability literacy test, an environmental awareness questionnaire, and observation sheets, then analyzed using the N-Gain test and an independent-samples t-test. The results demonstrated that the average sustainability literacy score in the experimental group increased from 56.80% to 84.10%, with an N-Gain of 0.63 (moderate), while the control group improved from 55.30% to 72.40%, with an N-Gain of 0.38 (moderate). Hypothesis testing indicated a significant difference between the two groups ($p = 0.003$; $p < 0.05$). Additionally, students' environmental awareness in the experimental group achieved an average score of 4.28 (very high), significantly higher than the control group's 3.65 (high), with a significance value of $p = 0.002$, $p < 0.05$). These findings demonstrate that integrating peatland ethnoscience into an Eco-Gamified PBL framework effectively enhances students' sustainability competencies. This study provides empirical evidence for integrating local ecological knowledge and gamification into problem-based learning to support contextualized sustainability education.
Keywords: Eco-gamification Environmental awareness Peatland ethnoscience PBL Sustainability literacy	
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INTRODUCTION

Environmental education at the junior high school level plays a strategic role in fostering sustainability literacy from an early age. Secondary education represents a pivotal stage for shaping students' awareness, attitudes, and pro-environmental behaviors (Ardoin et al.,

2020; Chen et al., 2022; Putra et al., 2021). Sustainability literacy is characterized by the mastery of skills, values, and competencies that empower individuals to make responsible decisions to maintain ecological, social, and economic balance for both present and future generations (Santoso et al., 2021; Siddiq et al., 2020). At this level, students are in a critical phase of cognitive development, enabling them to comprehend the intricate relationships between human activities and global ecosystems (Haya et al., 2025). Furthermore, such literacy capacity allows students to not only recognize environmental issues but also cultivate critical thinking and act responsibly toward real-world challenges (Wals & Dillon, 2013). A pressing environmental issue requiring urgent curricular integration, particularly in Indonesia, is peatland conservation. Peatlands serve as vital carbon sinks, hydrological regulators, and biodiversity buffers, yet they remain highly susceptible to degradation and wildfires (Masganti et al., 2016; Yeny et al., 2022; Yuwati et al., 2021).

Peatlands are vital wetland ecosystems that play a pivotal role in global climate regulation due to their capacity to sequester vast amounts of carbon beneath the soil surface. Tropical peatlands, in particular, exhibit significantly higher carbon density than other terrestrial ecosystems; consequently, their degradation poses a substantial threat to the global climate equilibrium (Dohong et al., 2018; Leifeld & Menichetti, 2018). Such degradation not only leads to the loss of biodiversity and localized hydrological functions but also undermines global ecosystem stability through accelerated carbon emissions and systemic climatic disruptions (IPCC, 2023; Parish et al., 2008; Turetsky et al., 2016). Accordingly, peatland conservation has emerged as a critical imperative that must be integrated across various sectors—most notably education—as a strategic, long-term endeavor to mitigate environmental crises and climate change.

To mitigate low student engagement in studying complex and contextual environmental issues, innovative instructional frameworks are essential to bridge the gap between abstract scientific knowledge and meaningful learning experiences. The integration of ethnoscience and gamification is particularly pertinent to ecology education, as both paradigms position students as active agents in their own learning. An ethnoscience-based approach allows students to synthesize formal scientific concepts with local wisdom regarding sustainable environmental stewardship, including traditional peatland management practices (Hikmawati et al., 2021; Suryanti et al., 2021; UNESCO, 2017). Concurrently, gamification leverages ludic elements—such as challenges, immediate feedback, and reward systems—to transform ecology learning into a highly interactive and immersive experience.

From a theoretical perspective, this integration is anchored in several established educational paradigms. Problem-Based Learning (PBL) is grounded in cognitive constructivism, which asserts that learners actively construct knowledge through authentic problem-solving and inquiry-based processes. Concurrently, the ethnoscience approach aligns with sociocultural theory, emphasizing that cognitive development is fundamentally shaped by cultural contexts and social interactions within a community. Furthermore, the motivational mechanisms inherent in gamification are supported by Self-Determination Theory (SDT), which posits that intrinsic motivation is fostered when learners experience autonomy, competence, and relatedness. By synthesizing these theoretical frameworks, a gamified learning environment can synergistically enhance students' intrinsic motivation, cognitive engagement, and agency in navigating and addressing complex, contextual environmental challenges (Hamari et al., 2014; Kalogiannakis et al., 2021; Sebastian et al., 2011).

However, previous research has predominantly examined ethnoscience-based learning and gamification as isolated constructs within science education. While ethnoscience has been extensively utilized to contextualize scientific principles through indigenous knowledge, and gamification has proven effective in bolstering student engagement, the

synergistic integration of these two paradigms within a cohesive pedagogical framework remains underexplored. Furthermore, current research primarily focuses on generalized environmental themes, often overlooking the specificities of peatland ecosystems—a unique and ecologically vital context, particularly within the Indonesian landscape. Consequently, there is a critical need for an integrated instructional model that bridges localized wisdom with modern motivational strategies to address these specialized environmental challenges.

PBL is an instructional model that situates authentic, real-world problems at the inception of the learning process, thereby prompting students to actively construct knowledge through systematic inquiry and collaborative discussion. Extant research indicates that PBL is highly effective in enhancing critical thinking, problem-solving competencies, and student engagement, particularly within complex and contextual domains such as science and ecology (Dolmans et al., 2016; Mutakinati et al., 2018; Aufa et al., 2021; Aufa et al., 2020). In the realm of environmental education, PBL facilitates the seamless integration of local wisdom through an ethnoscience approach, serving as a primary source of authentic problems while simultaneously bolstering engagement through gamification elements (Kalogiannakis et al., 2021; Yew & Goh, 2016).

Despite these advancements, research integrating ethnoscience, gamification, and PBL into a unified instructional framework remains scarce. In particular, there is limited empirical evidence examining how an eco-gamified PBL approach—grounded in local ethnoscience—can foster students' sustainability literacy and environmental awareness. Furthermore, previous research has rarely situated such pedagogical integration within the context of peatland ecology at the junior high school level, even though this educational stage is pivotal for shaping long-term environmental attitudes and behaviors.

Previous research has examined PBL integrated with ethnoscience and gamification as separate entities within science education. However, studies that integrate these approaches simultaneously within the context of peatland ecosystems at the junior high school level remain remarkably limited.

Therefore, the present study addresses this gap by integrating ethnoscience-based ecological knowledge with gamification elements within a Problem-Based Learning framework, specifically applied to peatland ecosystems. This integration is expected to facilitate a contextual, engaging, and culturally relevant learning experience that not only enhances students' comprehension of sustainability concepts but also fosters their environmental awareness regarding peatland conservation.

The present study aims to analyze how the implementation of an ethnoscience-based, Eco-Gamified PBL model within the context of peatland ecosystems enhances junior high school students' sustainability literacy. Furthermore, it examines the subsequent impact on environmental awareness regarding peatland conservation, specifically focusing on the transformation of cognitive understanding into pro-environmental attitudes and sustainable actions.

METHODS

Research Design and Procedures

This study employed a quasi-experimental design with a non-equivalent control group to assess the effects of an ethnoscience-based, Eco-Gamified PBL model on junior high school students' sustainability literacy and environmental awareness. The study involved two groups: Grade VIIB (32 students) at SMP Muhammadiyah Palangka Raya served as the experimental group, receiving instruction through the ethnoscience-based Eco-Gamified PBL model on peatland topics. Meanwhile, Grade VIIA (33 students) at the same institution functioned as the control group and received conventional instruction. The selection of these

classes followed an intact classroom structure; consequently, random assignment of individual students was not feasible. These specific classes were selected because they demonstrated comparable academic performance based on prior science achievement records and were instructed by the same teacher to minimize instructional variability. Furthermore, pre-test scores were analyzed to confirm the initial equivalence between the experimental and control groups prior to the intervention.

Both groups were administered a pre-test prior to the treatment and a post-test following the intervention to assess improvements in the measured variables (Table 1). To ensure group equivalence, pre-test scores from both the experimental and control groups were statistically compared using an independent samples t-test. The analysis revealed no significant differences between the two groups at the baseline, indicating that they were relatively equivalent before the treatment was implemented. The application of a quasi-experimental design with a pre-test/post-test pattern is considered an effective approach for measuring changes in learning outcomes and student attitudes following the implementation of innovative instructional models in school settings (Aripin et al., 2024; Roshayanti, 2019; Hasani et al., 2024). The detailed procedure of this study is illustrated in Figure 1.

Table 1 Non-equivalent pretest–posttest control group design

Group	Pre-test	Treatment	Post-test
Experimental	Q1	X: Eco-Gamified PBL Integrating Ethnoscience	Q2
Control	Q3		Q4

(Sugiyono, 2019)

Notes:

Q1 : Pre-test (initial observation) of the experimental group

Q2 : Post-test (final observation) of the experimental group

X : Intervention using the ethnoscience-based Eco-Gamified PBL model

Q3 : Pre-test (initial observation) of the control group

Q4 : Post-test (final observation) of the control group

The intervention was conducted over five instructional sessions, each lasting approximately 90 minutes. The learning activities focused on peatland ecosystem topics, specifically peatland characteristics, ecological functions, environmental challenges associated with peatland degradation, and conservation strategies. The same duration and curriculum content were applied to the control group; however, the instructional process was delivered through conventional methods without the integration of gamification or ethnoscience-based frameworks.

The ethnoscience-based Eco-Gamified PBL model synthesized local ecological knowledge of peatland management with problem-based learning activities. The gamification framework incorporated elements such as points, badges, and leaderboards, which were implemented via a web-based platform titled Guardian of Gambut. Within this platform, students performed environmental “missions” specifically designed to address real-world peatland conservation challenges.

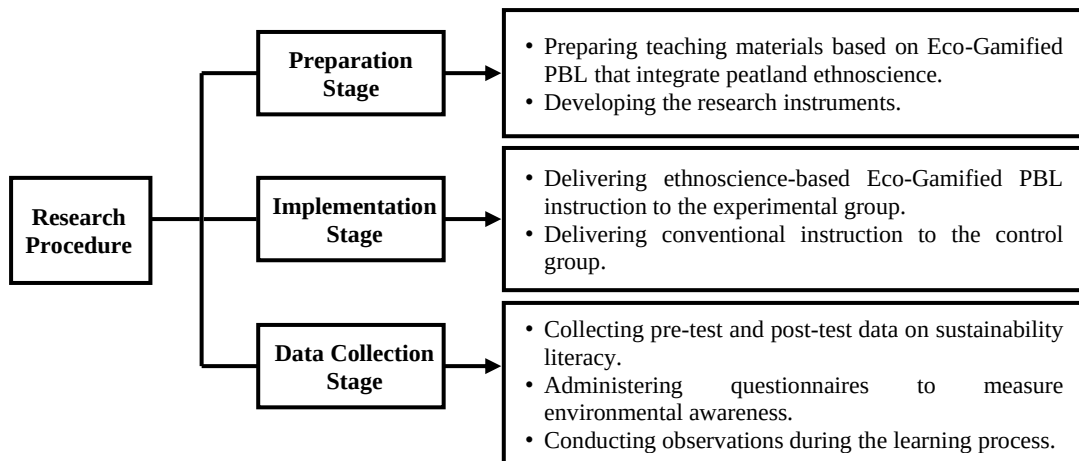


Figure 1 Research Procedure

Instruments

The instruments employed in this study comprised a sustainability literacy test, an environmental awareness questionnaire, and an observation sheet. The sustainability literacy test was administered to evaluate students' comprehension of ecological concepts, peatland conservation, and sustainability principles through pre- and post-test assessments. The environmental awareness questionnaire was utilized to assess students' attitudes and pro-environmental behaviors toward conservation in their daily lives, while the observation sheet served to monitor student engagement throughout the instructional process. To ensure the quality of the data, all three instruments were subjected to rigorous validity and reliability testing prior to their application.

Content validation was conducted through expert judgment, involving three ecology specialists and three science education experts to ensure alignment between instrument items, indicators, and research objectives. These experts evaluated each item based on relevance, clarity, and construct suitability. The validation results were quantified using expert ratings, with items categorized according to the feasibility criteria presented in Table 2. Furthermore, reliability was assessed using Cronbach's Alpha coefficient to determine the internal consistency of the sustainability literacy test and the environmental awareness questionnaire. The instruments were deemed reliable if they yielded a coefficient value of ≥ 0.70 , confirming their suitability for data collection in this study (Sugiyono, 2019; Widoyoko, 2018).

Data Analysis Technique

The results of the sustainability literacy test were categorized based on learning mastery levels using percentage criteria adapted from Arikunto (2018). Concurrently, the environmental awareness questionnaire data were analyzed using a Likert scale and interpreted according to established environmental awareness levels (Rohmad, 2021). The classification systems for both the sustainability literacy test and the environmental awareness questionnaire are presented in Tables 2 and 3, respectively.

Table 2 Students' sustainability literacy categories

Value Range	Category
81 – 100	Very Good
61 – 80	Good
41 – 60	Moderate
21 – 40	Poor
0 – 20	Very Poor

(Arikunto, 2018)

Table 3 Environmental awareness categories

Value Range	Category
4.21 – 5.00	Very Caring
3.41 – 4.20	Caring
2.61 – 3.40	Moderately Caring
1.81 – 2.60	Less Caring
1.00 – 1.80	Not Caring

(Rohmad, 2021)

The improvement in students' sustainability literacy was evaluated using normalized gain (N-gain) scores to determine the effectiveness of the instructional models implemented in both the experimental and control groups. The N-gain score was calculated by determining the difference between the pre-test and post-test scores, normalized against the maximum possible score, using the following formula:

$$N - Gain = \frac{Posttest - Pretest}{Maximum\ Score - Pretest} \quad (1)$$

The calculated N-Gain results were interpreted according to the categories presented in Table 4.

Table 4 N-Gain test categories

N-Gain Score	Category
≥ 0.70	High
0.30 – 0.69	Moderate
< 0.30	Low

(Hake, 1999)

A normality test was assessed using the Shapiro–Wilk test, and a homogeneity test was evaluated using Levene's test at a significance level of 0.05 prior to performing the independent-samples t-test. The data were considered normal and homogeneous when the significance value exceeded 0.05.

Quantitative analysis was performed using the independent-samples t-test to assess differences in pre- and post-test results between the experimental and control groups. Concurrently, qualitative analysis of observation and questionnaire data was conducted to identify changes in students' environmental awareness throughout the instructional process. The application of the t-test in experimental educational research aims to determine the significance of differences in learning outcomes between groups receiving distinct treatments (Sugiyono, 2019). Decision-making in hypothesis testing was based on comparing the significance value (Sig.) with a significance level of 0.05. If Sig. < 0.05 , there is a significant difference between the experimental and control groups; whereas if Sig. ≥ 0.05 , there is no significant difference between the two groups (Widoyoko, 2018).

RESULTS AND DISCUSSION

This section presents the statistical findings regarding students' sustainability literacy and environmental awareness following the implementation of the ethnoscience-based Eco-Gamified PBL model. The results encompass instrument validity and reliability, sustainability literacy test scores, and environmental awareness outcomes for both the experimental and control groups.

Students' Sustainability Literacy Results

The results of the students' sustainability literacy test were obtained from pre- and post-tests administered to both the experimental and control groups. The improvement in students' sustainability literacy was then analyzed using N-Gain to assess the effectiveness of the learning model implemented in each group. The sustainability literacy test results are presented in Table 5.

Table 5 Sustainability literacy test results

Group	Pre-test (%)	Category	Post-test (%)	Category	N-Gain	Category
Experimental	56.80	Fair	84.10	Very Good	0.63	Moderate
Control	55.30	Fair	72.40	Good	0.38	Moderate

Based on Table 5, the average pre-test score of the experimental group was 56.80% (Fair) and increased to 84.10% (Very Good) after the implementation of the ethnosience-based Eco-Gamified PBL model. Meanwhile, the control group obtained an average pre-test score of 55.30% (Fair), which increased to 72.40% (Good) following conventional instruction. Furthermore, the N-Gain calculation showed that the experimental group scored 0.63 (Moderate), whereas the control group scored 0.38 (Moderate). This indicates that the improvement in students' sustainability literacy in the experimental group was greater than that in the control group following the intervention.

A normality test was conducted using the Shapiro–Wilk test at a 0.05 significance level. The test was performed on the post-test sustainability literacy data for both the experimental and control groups. The results of the sustainability literacy normality test are presented in Table 6.

Table 6 Sustainability literacy normality test

Group	Sig. (Shapiro–Wilk)	Description
Experimental	0.087	Normal
Control	0.094	Normal

Based on Table 6, the significance value (Sig.) for the experimental group was 0.087, and for the control group, it was 0.094. Since both values are greater than 0.05 (Sig. > 0.05), it can be concluded that the sustainability literacy test data for both groups were normally distributed.

A homogeneity test was conducted using Levene's test at a 0.05 significance level. Based on the results, the obtained significance value (Sig.) was 0.126, which is greater than 0.05 (Sig. > 0.05). This indicates that the variance of the sustainability literacy data in both the experimental and control groups was homogeneous.

Hypothesis testing was conducted using an independent-samples t-test to assess the significance of differences in sustainability literacy results between the experimental and control groups. The results of the sustainability literacy hypothesis test are presented in Table 7.

Table 7 Sustainability literacy hypothesis test

Variable	Sig. (2-tailed)	Description
Sustainability Literacy	0.003	Significant Difference

Based on the results of the independent-samples t-test shown in Table 7, the significance value (Sig. 2-tailed) was 0.003, which is less than 0.05 (Sig. < 0.05). This indicates a significant difference in sustainability literacy results between the experimental and control groups following the intervention, suggesting that the ethnosience-based Eco-Gamified PBL model on peatlands significantly improved students' sustainability literacy.

Students' Environmental Awareness Results

Students' environmental awareness was assessed using questionnaires distributed to both the experimental and control groups after the learning process. Environmental awareness data were analyzed using mean Likert scores to evaluate students' concern for environmental conservation. The results are presented in Table 8.

Table 8 Environmental awareness test results

Group	Mean Score	Category
Experimental	4.28	Very Caring
Control	3.65	Caring

Based on Table 8, the average environmental awareness score for students in the experimental group was 4.28 (Very Caring), while the control group averaged 3.65 (Caring). These results indicate that the level of environmental awareness among students in the experimental group was higher than that of the control group following the implementation of the ethnosience-based Eco-Gamified PBL model on peatlands.

However, environmental awareness in this study was measured only after the intervention using a self-report questionnaire. Since baseline environmental awareness levels were not assessed prior to the treatment, the findings should be interpreted cautiously, as pre-existing differences between the experimental and control groups cannot be entirely ruled out.

A normality test was conducted using the Shapiro–Wilk test at a 0.05 significance level. The test was performed on the post-test environmental awareness data for both the experimental and control groups. The results of the environmental awareness normality test are presented in Table 9.

Table 9 Environmental awareness normality test

Group	Sig. (Shapiro–Wilk)	Description
Experimental	0.076	Normal
Control	0.082	Normal

Based on Table 9, the significance value (Sig.) for the experimental group was 0.076, and for the control group, it was 0.082. Since both values are greater than 0.05 (Sig. > 0.05), it can be concluded that the environmental awareness data for both groups were normally distributed.

A homogeneity test was conducted using Levene's test at a 0.05 significance level. Based on the results, the obtained significance value (Sig.) was 0.139, which is greater than 0.05 (Sig. > 0.05). This indicates that the variance of the environmental awareness data in both the experimental and control groups was homogeneous.

Hypothesis testing was conducted using an independent-samples t-test to assess the significance of differences in environmental awareness results between the experimental and control groups. The results of the environmental awareness hypothesis test are presented in Table 10.

Table 10 Environmental awareness hypothesis test

Variable	Sig. (2-tailed)	Description
Environmental Awareness	0.002	Significant Difference

Based on the results of the independent-samples t-test shown in Table 10, the significance value (Sig. 2-tailed) was 0.002, which is less than 0.05 (Sig. < 0.05). This indicates a significant difference in environmental awareness results between the experimental and control groups following the intervention, suggesting that the ethnosience-based Eco-Gamified PBL model on peatlands significantly improved students' environmental awareness.

The Effect of Ethnoscience-Based Eco-Gamified PBL on Sustainability Literacy

The results of this study indicate that the implementation of the ethnoscience-based Eco-Gamified PBL model on peatlands significantly improves junior high school students' sustainability literacy. This is evidenced by the higher average post-test scores in the experimental group compared to the control group, as well as a significance value of 0.003 (Sig. < 0.05) from the independent-samples t-test, which confirms a significant difference between the two groups following the intervention. The improvement in sustainability literacy in the experimental group was also demonstrated by an N-Gain value of 0.63 (Moderate), which was higher than the control group's N-Gain of 0.38 (Moderate). These findings suggest that the implementation of the ethnoscience-based Eco-Gamified PBL model on peatlands is more effective in enhancing students' understanding of sustainability concepts compared to conventional learning approaches.

Although the N-Gain value in the experimental group was higher than that of the control group, the improvement remained in the moderate category. This result may be influenced by several factors. First, the duration of the intervention was relatively short, consisting of only a limited number of learning sessions, which may not have been sufficient to produce a higher level of conceptual change. Second, students' prior knowledge regarding peatland ecosystems and sustainability concepts may have varied, potentially affecting the extent to which they were able to construct new knowledge during the learning process. Third, the complexity of peatland ecology—which involves interconnected ecological processes and environmental issues—may have increased students' cognitive load when attempting to grasp these concepts within a limited instructional timeframe.

Pedagogically, the improvement in students' sustainability literacy may occur because the PBL model utilizes real-world problems as the starting point of the learning process, thereby encouraging students to actively construct knowledge through inquiry, group discussions, and contextual problem-solving (Dolmans et al., 2016). The integration of an ethnoscience approach further enables students to relate scientific concepts to local environmental practices—particularly in peatland management—making the learning process more meaningful and relevant to their daily lives (Suryanti et al., 2021). Additionally, the implementation of gamification elements contributes to increasing students' intrinsic motivation and engagement. Elements such as challenges, feedback, and reward systems create a more interactive and participatory environment, allowing students to become more actively involved in understanding complex environmental issues, such as peatland conservation (Hamari et al., 2014; Kalogiannakis et al., 2021). Consequently, the synergy between PBL, ethnoscience, and gamification within the Eco-Gamified PBL model provides a robust framework for effectively enhancing students' sustainability literacy.

This study is consistent with the findings of Subhash & Cudney (2018) and Ardoin et al. (2020), which state that integrating gamification elements into problem-based learning can enhance students' cognitive engagement and promote a deeper conceptual understanding of environmental issues. Furthermore, research by Mutakinati et al. (2018) demonstrates that the implementation of PBL in science education positively affects students' problem-solving skills and environmental literacy. Moreover, Yew & Goh (2016) revealed that the PBL model is effective in improving students' critical thinking skills and conceptual understanding through a learning process centered on real-world problem-solving. These findings support the results of the present study, indicating that implementing the ethnoscience-based Eco-Gamified PBL model on peatlands significantly improves students' sustainability literacy.

From a curriculum perspective, the findings of this study suggest that integrating contextual environmental issues—such as peatland ecosystems—into science education can support the development of students' sustainability literacy. Curriculum designers should

consider incorporating local environmental contexts and problem-based learning activities to promote meaningful learning experiences. This approach aligns with the principles of transformative and contextual learning in Education for Sustainable Development (ESD), ensuring that sustainability concepts are not only understood theoretically but also applied within relevant local frameworks.

In terms of environmental education policy, these results highlight the necessity of strengthening programs that bridge scientific knowledge with local ecological issues. Learning models that integrate ethnoscience and environmental problem-solving can contribute to fostering students' awareness and understanding of sustainable environmental management. This is particularly vital in regions where peatland ecosystems play a significant ecological role, suggesting that policy frameworks should prioritize localized, context-driven educational strategies.

Furthermore, these findings imply the necessity of teacher training programs that equip educators with the skills to implement innovative models, such as Eco-Gamified PBL. Teachers require adequate pedagogical knowledge to design problem-based activities, integrate local wisdom into science education, and effectively apply gamification strategies to enhance student engagement in environmental education.

The Effect of Ethnoscience-Based Eco-Gamified PBL on Environmental Awareness

The results of the study indicate that implementing the ethnoscience-based Eco-Gamified PBL model on peatlands significantly improves students' environmental awareness. This is demonstrated by the higher average awareness scores in the experimental group compared to the control group, as well as the independent-samples t-test results, which show a significance value of 0.002 (Sig. < 0.05). These results confirm a significant difference in environmental awareness between the two groups following the intervention. The improvement in the experimental group may be attributed to students' active involvement in the problem-based learning process, which addressed real-world environmental issues, particularly those related to peatland conservation. Through collaborative discussions and problem-solving activities, students not only gained a conceptual understanding of sustainability but also developed a heightened sense of responsibility for their surrounding environment.

The ethnoscience approach integrated into the learning process also plays a pivotal role in fostering students' environmental awareness by linking scientific concepts with local wisdom in sustainable environmental management. Contextual learning that is relevant to students' daily lives facilitates a connection between acquired knowledge and the attitudes or behaviors demonstrated in real-life situations. In addition, the implementation of gamification elements enhances students' emotional engagement, thereby encouraging the development of deeper environmental awareness. Consequently, the implementation of the ethnoscience-based Eco-Gamified PBL model on peatlands not only improves cognitive aspects—such as sustainability literacy—but also contributes significantly to the development of environmental awareness as a vital component of sustainable conservation efforts.

The findings of this study are supported by previous research indicating that PBL combined with contextual approaches can improve students' environmental awareness and attitudes. A study by [Febriasari & Supriatna \(2017\)](#) demonstrated that the implementation of PBL in environmental education enhances environmental literacy and sustainability awareness through active involvement in solving real-world ecological issues. Furthermore, [Dicheva et al. \(2015\)](#) explained that gamification elements increase students' motivation and emotional engagement, which contributes to the development of positive attitudes and behaviors toward the environment. Therefore, the results of this study reinforce previous

findings that integrating problem-based and gamification approaches possesses the potential to improve students' environmental awareness more effectively.

Research Limitations

Despite the positive findings, this study possesses several limitations that should be considered when interpreting the results. First, the research was conducted within a single school, which may limit the generalizability of the findings to broader educational contexts. Second, the duration of the intervention was relatively short, potentially influencing the magnitude of the observed learning improvements. A more extended implementation period might provide a more comprehensive understanding of the long-term effects of the Eco-Gamified PBL model on students' sustainability literacy and environmental awareness.

In addition, environmental awareness in this study was measured only after the intervention using a self-report questionnaire. Since baseline environmental awareness levels were not assessed prior to the treatment, the findings should be interpreted cautiously, as pre-existing differences between the experimental and control groups cannot be entirely ruled out. Future research is recommended to employ both pre-test and post-test measurements of environmental awareness and to involve a larger number of schools. Such efforts would provide stronger evidence regarding the effectiveness of the ethnoscience-based Eco-Gamified PBL model in environmental education.

CONCLUSION

The findings of this study indicate that the implementation of the ethnoscience-based Eco-Gamified PBL model on peatlands is associated with significant improvements in junior high school students' sustainability literacy and environmental awareness compared to conventional learning. The integration of PBL, ethnoscience, and gamification—within the contextual framework of peatland ecosystems—supports students' understanding of sustainability concepts while fostering a greater awareness of environmental conservation. These results suggest that incorporating local environmental contexts and interactive learning strategies into science instruction contributes to more meaningful sustainability education. However, these findings should be interpreted with caution due to the study's limited scope, including its execution in a single school, a relatively short intervention period, and the use of post-intervention self-reports for measuring awareness. Consequently, future research involving larger samples, extended implementation periods, and more comprehensive longitudinal measurements is recommended to further validate the effectiveness of this model.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, MNA and GNN; methodology, MNA, GNN, and MH; software, MH; validation, R; formal analysis, GNN and R; investigation, MNA and GNN; resources, MNA; data curation, MH and R; writing—original draft preparation, MNA; writing—review and editing, GNN and MH; visualization, R; supervision, MNA; project administration, MNA; funding acquisition, MNA. All authors have read and agreed to the published version of the manuscript.

AI DISCLOSURE STATEMENT

During the preparation of this work, the authors used ChatGPT (Artificial Intelligence or AI) for language refinement and assistance with structuring certain sections of the

manuscript. Following the use of this tool, the authors thoroughly reviewed, edited, and validated the content to ensure accuracy and academic integrity. The authors take full responsibility for the final content of the publication and declare that the core research, data analysis, and interpretations were conducted without the aid of artificial intelligence.

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AUTHOR PROFILES



Mohamad Nor Aufa is a lecturer at Universitas Muhammadiyah Palangkaraya who is actively engaged in research and the development of technology and local wisdom-based contextual learning innovations. Email: mohamadnoraufa@umpr.ac.id SINTA ID: 6937731 Scopus ID: 57217927455



Gusti Nida Nurkhaliza is a lecturer at Muhammadiyah University of Palangka Raya, specializing in research on the development of technology-based learning media. Her work focuses on integrating digital tools to improve educational effectiveness. Email: nidanurkhaliza@gmail.com SINTA ID: 6949458



Muhammad Hasbie is a lecturer at STAI Al Falah Banjarbaru, specializing in research on the development of context-based learning in science and education, including science modules and innovative learning approaches to improve student understanding. Email: muhammadhasbie11@gmail.com Scopus ID: 57222350155



Rusmansyah is a lecturer at Lambung Mangkurat University, South Kalimantan, Indonesia. He is a lecturer in the Department of Chemistry Education, Faculty of Teacher Training and Education, Lambung Mangkurat University, Banjarmasin. Email: rusmansyah@ulm.ac.id, Sinta ID: 6043801. Scopus ID: 57206663448