Vol. XI No. 1 June 2025
DOI: https://doi.org/10.19109/bioilmi.v11i1.28551
E-ISSN: 2527-3760
Page: 42 - 51

Peatland Biodiversity Learning through Virtual Reality: a Case Study at Muhammadiyah Palangka Raya University

Feni Rosdiani*, Kurnia Dewi, Senopi, Murni, Melan Yutiva, Imelda, Fathul Zannah, Rezky Aulianur Syahbana

Biology Education, Faculty of Languages, Science and Technology, Muhammadiyah Palangka Raya University

*fenirosdiani92@gmail.com *(Corresponding Author)*

ARTICLE INFO

***Article history*:**
Received: 24/05/2025
Revised: 11/06/2025
Accepted: 27/06/2025

***Keywords*:**
Biodiversity
Environmental Education
Immersive Learning
Peatland Ecosystem
Virtual Reality

ABSTRACT

Tropical peatland ecosystems are ecologically important yet often neglected in formal biology education due to accessibility and logistical limitations. In Central Kalimantan, where peatland biodiversity is rich but difficult to observe directly, students face challenges in understanding complex ecological interactions and local environmental issues. This study examined the effectiveness of Virtual Reality (VR) as an immersive learning tool to enhance students' conceptual understanding, engagement, and ecological awareness. A mixed-methods exploratory-descriptive design was employed involving 14 undergraduate students from the Biology Education program at Universitas Muhammadiyah Palangka Raya. Participants interacted with a custom-developed VR module titled *"Exploring Peatland Biodiversity"* during two guided sessions over two weeks. Data were collected through pre- and post-tests, observation checklists, and focus group discussions (FGDs). Results showed a significant increase in students' learning outcomes, with average test scores rising from 56.93 (pre-test) to 81.79 (post-test). A paired samples t-test confirmed the improvement as statistically significant (mean difference = 24.86, $p < 0.001$). Qualitative findings revealed that students perceived the VR module as realistic and emotionally engaging. They demonstrated improved species recognition, understanding of ecological processes, and awareness of threats such as deforestation and peat fires. The study concludes that VR offers an effective solution for biodiversity learning in remote and fragile ecosystems, enhancing both knowledge and environmental concern.

INTRODUCTION

Peatland ecosystems are among the most significant and vulnerable ecological systems on Earth (Pratiwi et al., 2021). Characterized by water-saturated conditions and thick organic soil layers formed over thousands of years, peatlands play a crucial role in regulating global climate through carbon sequestration, supporting high levels of biodiversity, and sustaining hydrological balance (Syahza et al., 2020). Indonesia, particularly the island of Kalimantan, harbors one of the largest tropical peatland areas in the world, with Central Kalimantan recognized as a critical hotspot for peat biodiversity (Striner & Preece, 2018). However, these ecosystems are under constant threat from deforestation, drainage, and fires, exacerbated by low levels of environmental awareness and education regarding their ecological importance (Taufik et al., 2019).

Palangka Raya, the capital city of Central Kalimantan, is geographically and ecologically intertwined with peatland landscapes (McMillan et al., 2017). As such, it offers a unique opportunity for local universities to serve as centers of excellence in peatland education and conservation (Lo & Tsai, 2022). Universitas Muhammadiyah Palangka Raya (UMPR), through its

Faculty of Education and Science and Biology Education undergraduate program, has made peatland conservation one of its academic and research priorities (Rambach et al., 2020). However, field-based learning, which is essential for understanding biodiversity in peat ecosystems, faces several challenges ranging from limited access to peat sites, logistical constraints, safety concerns due to peat fires, and the fragile condition of the environment itself (Sari'ani et al., 2024).

Virtual Reality (VR) has emerged as a promising innovation in science education, offering immersive and interactive simulations that replicate real-world environments. In biodiversity learning, VR enables students to explore complex ecosystems such as tropical peatlands without the logistical, environmental, or safety constraints of direct fieldwork. Through 360° visualization and user interaction, VR supports active learning by enabling learners to observe species, examine ecological processes, and experience environmental scenarios in ways that traditional media cannot. Several studies support its pedagogical benefits: Chang et al. (2020) and Cheng & Tsai (2021) highlighted VR's ability to boost student motivation and ecological empathy, while Wojciechowski and Cellary (2013) found significant improvements in students' conceptual retention through VR-based instruction. Rahman et al. (2022) further emphasized how virtual laboratories contribute to deeper understanding of biological systems (Rodriguez & Davis, 2024) Despite these promising outcomes, most existing studies are conducted in well-resourced institutions and focus on general environmental education topics, with limited attention to region-specific biodiversity or marginalized ecosystems like Southeast Asian peatlands (Page, 2021).

Moreover, there is a research gap regarding the contextual implementation of VR in underrepresented ecological zones such as Kalimantan's peat swamp forests, especially within regional universities. Previous studies have rarely examined how locally grounded VR content featuring endemic species and conservation challenges unique to a specific region can influence student learning and ecological awareness. This study addresses that gap by focusing on the integration of VR in biodiversity education at Universitas Muhammadiyah Palangka Raya (UMPR), leveraging immersive technology to simulate the rich yet threatened peatland ecosystems of Central Kalimantan. By exploring how VR can be tailored to support place-based environmental education, this research offers both practical insights and theoretical contributions to the growing discourse on digital innovation in sustainability learning.Within the context of Palangka Raya, the application of VR in biodiversity education aligns with both the regional environmental challenges and the national push toward digital transformation in higher education (Mulders et al., 2025). Moreover, the digital documentation of peatland species many of which are endemic and under threat can contribute to a long-term virtual repository that supports both academic and conservation goals (Rahman & Dewi, 2022). Implementing VR-based modules that simulate real peatland environments also enables students to identify species, observe ecological interactions, and learn conservation strategies in a safe and engaging way (Nuroniah et al., 2021). Despite the potential of VR in enhancing biodiversity education, its implementation in Indonesian higher education, particularly in regional universities like UMPR, remains limited. There is a lack of empirical studies documenting the process, outcomes, and challenges of integrating VR in environmental science curricula. Additionally, local biodiversity data are often underrepresented in educational content, highlighting the need for context-specific virtual learning environments that reflect the richness of Kalimantan's peatland ecosystems (Meng et al., 2024)(Sinaga et al., 2024).

Therefore, this article seeks to explore the implementation of Virtual Reality in biodiversity learning at Universitas Muhammadiyah Palangka Raya, focusing on the peatland ecosystem as a case study. The study aims to examine the pedagogical impact, student perceptions, and the potential of VR to foster ecological awareness and conservation ethics among future educators. Through this initiative, it is expected that digital innovation can bridge the gap between ecological theory and environmental action, while strengthening the role of local universities in preserving Indonesia's peatland heritage.

MATERIALS AND METHODS

1. Time and Place of Research

The research was conducted from August to November 2024 at the Digital Learning Laboratory, Biology Education Study Program on FBIT Muhammadiyah Palangka Raya University (UMPR), located in Central Kalimantan, Indonesia. The site was selected due to its ecological relevance to peatland ecosystems and the institution's focus on environmental and biodiversity education.

2. Type and Method of Research

This study employed a mixed-methods approach with an exploratory-descriptive design, integrating both quantitative and qualitative data to analyze the implementation of Virtual Reality (VR) as a learning innovation. The mixed-methods strategy allowed for in-depth analysis of learning outcomes and student perceptions within a contextualized biodiversity learning experience.

3. Instruments and Materials of Research

The materials and instruments used in this study included Meta Quest 2 VR headsets and a specialized VR module entitled "Exploring Peatland Biodiversity", developed using Unity 3D. The module simulated an immersive 360° environment of a tropical peat swamp forest in Central Kalimantan. The interactive content included species identification (e.g., *Nepenthes spp.*, *Shorea spp.*, orangutans), ecosystem interaction visualizations (e.g., food webs, carbon cycle), and simulated conservation issues (e.g., peat fires, illegal logging). Data collection tools consisted of a cognitive test (pre- and post-tests), observation checklists, and a Focus Group Discussion (FGD) guide.

4. Population and Sample

The population in this study comprised students enrolled in the "Biodiversity of Tropical Ecosystems" course at UMPR. A purposive sample of 14 undergraduate students was selected, with the criteria that participants had no prior experience with peatland field studies. This was intended to measure the impact of the VR module on students who were completely unfamiliar with the peatland environment.

5. Research Procedure

Research procedure was divided into three stages: (1) preparation, (2) implementation, and (3) evaluation. During the preparation stage, the research team developed the VR module, constructed assessment tools, and conducted a trial to ensure technical readiness. In the implementation stage, students first completed a pre-test to measure initial knowledge levels, followed by an orientation session on the VR system. Subsequently, they participated in two guided VR learning sessions (60 minutes each) over two weeks. During the sessions, students explored the virtual environment, interacted with learning elements, completed embedded quizzes, and made ecological observations. In the evaluation stage, students completed a post-test and participated in FGDs to provide reflective feedback on their experiences (Figure 1.). The sequence of implementation followed recommendations for immersive environmental learning design, particularly in structuring cognitive engagement and reflection phases (Lo & Tsai, 2022)

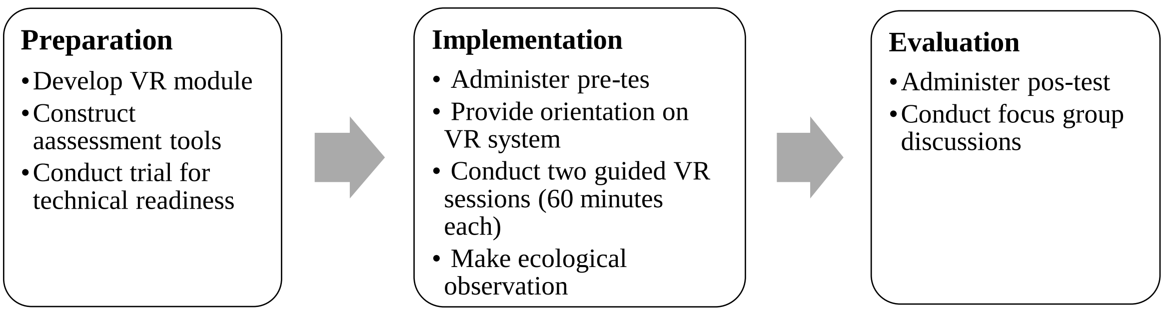

Figure 1. Flow of Research Procedur

6. Data Collection Techniques

Data collection techniques included a cognitive test comprising 20 multiple-choice and 5 short-answer items on peatland biodiversity, administered before and after the intervention. Observation checklists were completed by facilitators to record student activity, interaction, and responses during VR sessions. Focus Group Discussions (FGDs) were used to explore students' perceptions, emotional engagement, and suggestions for further development of the VR learning model.

7. Data Analysis Techniques

Quantitative data were analyzed using paired sample t-tests via SPSS to identify statistically significant differences between pre- and post-test scores. Meanwhile, qualitative data from FGDs were examined using thematic analysis to identify recurring themes related to ecological awareness, immersion, and usability. Triangulation was applied across test results, observational data, and FGD responses to ensure the credibility and validity of the findings.

RESULTS AND DISCUSSION

The results of the study revealed a significant improvement in students' understanding of peatland biodiversity following the implementation of the VR-based learning module. Quantitative data were obtained from 14 participants through pre-test and post-test assessments, with 25 items in total (20 multiple-choice and 5 short-answer questions). The scores of each participant were analyzed using SPSS 25.0 to determine the statistical significance of learning gains. The individual pre-test and post-test scores for all participants, these findings suggest that the use of immersive virtual environments facilitated deeper conceptual understanding and retention of biodiversity-related knowledge, particularly regarding species identification, ecosystem interactions, and conservation threats within peat swamp forests. Observational data collected during the VR sessions further supported these findings. Students exhibited high levels of engagement, curiosity, and interaction with the learning environment. Most participants actively explored the virtual forest, revisiting hotspots such as areas containing orangutan habitats, carnivorous pitcher plants (*Nepenthes spp.*), and canopy-level tree species (*Shorea spp.*). Notably, many students demonstrated increased motivation to learn outside of class, with some expressing interest in visiting real peatland areas as a follow-up to their VR experience (Zhao & Sun, 2025). This aligns with prior studies by Chang et al. (2020) and Cheng & Tsai (2021), which found that immersive technologies can enhance environmental attitudes and learning motivation by providing emotionally rich, memorable experiences (Pratiwi et al., 2021).

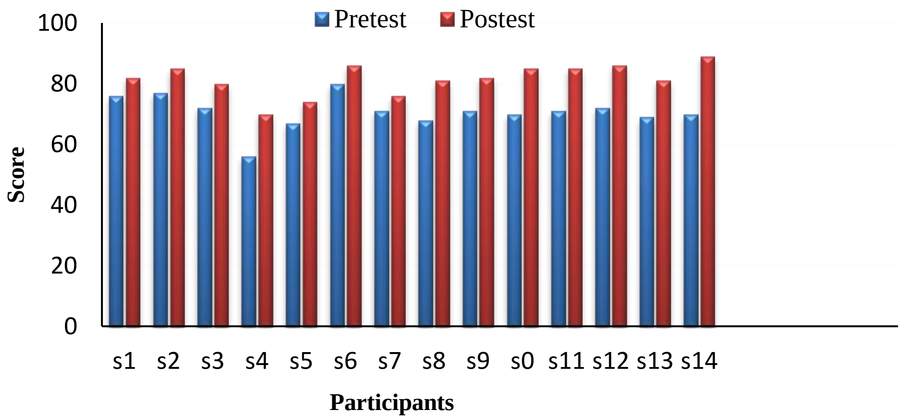

Figure 2. Pre-test and Post-test Scores of Participants (N = 14)

Figure 2 visually represents the individual scores of 14 student participants before and after engaging with the VR-based biodiversity learning module. The graph clearly illustrates a consistent and substantial improvement in post-test scores across nearly all participants. While pre-test scores varied and clustered in the lower range (between 50 and 60), post-test scores showed a marked upward trend, with the majority of students scoring above 80. This distribution pattern highlights not only the overall effectiveness of the VR module in enhancing conceptual understanding but also the uniform benefit experienced across different learners, regardless of their initial knowledge level. The upward trajectory across participants supports the statistical findings reported in Table 3, where a significant mean difference of 24.86 points ($p < 0.001$) was observed. The visual evidence provided in this figure aligns with previous research emphasizing the impact of immersive technologies on learning outcomes (Chang et al., 2020; Herwidiah et al., 2024). Furthermore, the consistently improved scores indicate that immersive VR modules can be a powerful equalizing tool in environmental education, helping students with diverse academic backgrounds achieve meaningful learning gains.

Tabel 1. Pre-test and Post-test Scores of Participants (N = 14)

Test Type	Mean Score
Pre-test	56.93
Post-test	81.79

Table 1 shows the descriptive statistics of student learning outcomes before and after the VR-based intervention. The increase in mean scores from 56.93 (pre-test) to 81.79 (post-test) indicates a marked improvement in conceptual understanding of peatland biodiversity. This gain is consistent with Chang et al. (2020), who found that immersive learning environments increase student engagement and improve cognitive outcomes in science education. The low standard deviations in both tests suggest that the learning gains were consistent across the sample. These results align with Herwidiah et al. (2024), who emphasized the value of visual and spatial representations in supporting students' ability to retain ecological knowledge, especially in abstract and complex domains like biodiversity. This increase reflects higher conceptual retention, especially in taxonomy and ecological interaction, as emphasized in immersive learning literature (Herwidiah et al., 2024; Chang et al., 2020).

Tabel 2. Paired Result Sample of t-test to Pre-test and Post-test Score

Statistik	Pre-test	Post-test
N	14	14
Mean	56.93	81.79
Std. Deviation	1.73	2.03
Std. Error Mean	0.46	0.54

Table 2 reinforces the general trend in Table 1 by isolating the mean values, highlighting the 24.86-point improvement in learning outcomes. This improvement supports the assertion by Rahman et al. (2022) that virtual laboratories and immersive modules can bridge gaps in field-based experiences, especially in remote ecosystems like peatlands. The VR experience simulated key biodiversity features—such as Nepenthes spp., orangutans, and tropical tree canopies making ecological content more concrete and easier to grasp for students (Giesen & Wulffraat, 2018).

Tabel 3. Paired Samples Test

Test Type	Mean Difference	Std. Dev	Std. Error Mean	t	df	Sig. (2-tailed)
Post-test – Pre-test	24.86	1.17	0.31	80.09	13	.000*

Table 3 provides the inferential analysis confirming the significance of the learning improvement. The t-test result ($t = 80.09$; $p < 0.001$) shows a statistically significant difference between pre- and post-test scores. This result strengthens the conclusion that VR learning environments are effective in improving student comprehension of complex ecological topics. According to O’Neill (2019), immersive experiences foster a deeper cognitive and emotional connection to content, particularly in environmental education. The very small standard error (0.31) and low standard deviation suggest high reliability in the intervention's effectiveness, as also discussed in Situmorang et al. (2019), who observed similar patterns of consistent learning gains in immersive science learning contexts.

This study aimed to explore the pedagogical impact of Virtual Reality (VR) on biodiversity learning in peatland ecosystems, assess students' perceptions of immersive learning, and evaluate its potential in fostering ecological awareness and conservation ethics among prospective biology educators (Schaffner, n.d.). The results of the study affirm all three objectives, offering both quantitative and qualitative evidence of VR's effectiveness in transforming biology education (Wulandari, 2023).

Tabel 4. VR structure Module Video

Part	Module Video	Explanation
1		**Opening** Conten : Display of logos: Muhammadiyah University of Palangka Raya (UMPR), Faculty of Science, Technology, and Education (FBIT), Biology Education Program. Title overlay: "Exploring the Peatland Ecosystem – A 360° Immersive Experience"
2		**Explanation** Conten : Visual: Tall Shorea Orang Utan *(Spongo sp)* trees, Ramin *(Gonystylus sp.)*, Jelutung *(Dyera sp*.), *Nepenthes sp*, on the forest floor. Orangutans swinging on trees, hornbills flying overhead, long-tailed macaques at water edges
3		**Closing** Aerial 360° view of intact peat forest + overlay of institutional logos again

Table 4. outlines the pedagogical design of the VR module used in this study. The structured sequencing from institutional identity (opening), immersive biodiversity experience (main), to conservation reflection (closing) enhances narrative coherence and emotional engagement (Lo &

Tsai, 2022). Including iconic and endemic species of Central Kalimantan, such as Shorea spp. and orangutans, situates the learning within a local ecological context, supporting place-based environmental education (Aini et al., 2023; Nuroniah et al., 2021). This approach is critical in fostering not just knowledge acquisition, but also conservation ethics and regional ecological empathy (Sari'ani et al., 2024).

The integration of the VR-based module significantly improved students' cognitive understanding of tropical peatland biodiversity. A total of 14 students completed both the pre- and post-tests. The statistical analysis using a paired-sample t-test showed a significant increase in test scores (pre-test mean = 56.93; post-test mean = 81.79; $p < 0.001$). This 24.86-point gain indicates that immersive VR environments support deeper comprehension and retention, especially in complex ecological domains that are typically abstract when taught through conventional methods. Students were better able to identify native species such as Nepenthes spp. (pitcher plants), Shorea spp. (tropical hardwood trees), and orangutans. They also demonstrated improved understanding of ecological relationships, including food webs and nutrient cycles, as well as anthropogenic threats like illegal logging and peat fires. These findings support the growing body of literature affirming that immersive technology strengthens conceptual learning, especially when integrated within place-based ecological contexts (Herwidiah et al., 2024)(Fauziah et al., 2018).

Focus Group Discussions (FGDs) revealed overwhelmingly positive student perceptions toward the VR learning experience. Participants described the module as “realistic,” “engaging,” and “educationally eye-opening,” particularly for students who had never been to a real peatland (Leksono et al., 2021). The immersive nature of the experience elicited emotional responses especially when encountering virtual scenes of ecosystem degradation which enhanced students' empathy toward environmental issues (Shih et al., 2021). In alignment with the study's second objective, students reported that the interactive and exploratory design of the VR module helped them internalize abstract ecological concepts more meaningfully (Campos et al., 2024)(Rahmawati et al., 2022). The opportunity to "walk through" the virtual swamp and interact with various species made learning more memorable and personal. Several students also expressed increased motivation to pursue further environmental learning and conservation activities outside the classroom, highlighting VR's motivational power (Purwanti & Ardiansyah, 2019).

One of the most significant impacts observed aligns with the study's third objective: the potential of VR to nurture ecological awareness and conservation-mindedness (Situmorang et al., 2019) (Aini et al., 2023). Students reflected a newfound appreciation for the richness and fragility of peatland ecosystems, often expressing concern for local environmental degradation (Giesen & Wulffraat, 2018) The contextual design of the VR module which incorporated local species and realistic conservation scenarios from Central Kalimantan played a critical role in making the learning relevant and emotionally resonant. These findings echo previous studies (e.g., Chang et al., 2020; Lo & Tsai, 2022) that emphasize the role of immersive technologies in fostering environmental ethics. Not only did students gain factual knowledge, but they also demonstrated signs of value formation, such as recognizing the importance of protecting native biodiversity and voicing personal commitments to sustainable behavior. This highlights the promise of VR in shaping both cognitive and affective domains of sustainability education (O'Neill, 2019) (Sukardjo & Djuarsa, 2017).

While the study results were largely positive, some limitations were noted (Voss & Harper, 2020). A few students experienced mild disorientation during VR navigation, suggesting the need for improved interface design or onboarding tutorials (Schuyt & Brander, 2015). Furthermore, the small sample size and short intervention period limit the generalizability of findings. Future research should include longitudinal studies to examine behavioral impacts over time, as well as investigations into the scalability of VR modules in resource-limited institutions (Lin et al., 2019).

CONCLUSION

This study set out to investigate the pedagogical impact of Virtual Reality (VR) on biodiversity education, examine students' perceptions of immersive learning, and explore VR's potential to cultivate ecological awareness and conservation ethics. The findings strongly support all three objectives, with empirical data and descriptive insights. VR-based learning significantly improved students' conceptual understanding of peatland biodiversity. The average score increased from 56.93 in the pre-test to 81.79 in the post-test, with a statistically significant mean difference of 24.86 points ($p < 0.001$). This quantitative result confirms the effectiveness of immersive environments in facilitating deeper cognitive learning, particularly in identifying species, understanding ecological processes, and recognizing environmental threats. Observational data during the VR sessions indicated high levels of student engagement. Participants were actively involved in navigating the virtual peat forest, showing curiosity and motivation, especially when exploring hotspots such as orangutan habitats and pitcher plant zones. These behavioral indicators reflect the VR module's ability to promote active, inquiry-based learning. Qualitative findings from Focus Group Discussions revealed that students perceived the VR experience as realistic, meaningful, and emotionally engaging. Many expressed increased empathy toward environmental issues and a stronger desire to engage in real-world conservation efforts. Importantly, the inclusion of locally contextualized content featuring native species and region-specific ecological challenges enhanced the relevance and impact of the learning experience. Taken together, these results demonstrate that Virtual Reality is not merely an engaging technological tool but a pedagogically powerful medium capable of bridging gaps between abstract ecological theory and real-world environmental understanding. It offers an accessible and scalable solution for biodiversity education in regions where field access is limited, such as Central Kalimantan's peatlands. Future research is recommended to assess the long-term behavioral impact of immersive learning and its integration into broader curriculum frameworks.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to FBIT Universitas Muhammadiyah Palangka Raya (UMPR), for their support in facilitating this research. Special thanks go to the undergraduate students of the Biology Education Program who participated enthusiastically in this study. We also acknowledge the technical assistance provided by the Digital Learning Laboratory team in the development and implementation of the Virtual Reality module. This research would not have been possible without the collective contributions and commitment to innovation in environmental education.

REFERENCES

Aini, N., Herdina, G. G. H., & Nasrullah, N. S. (2023). GARY Game-Library: Digital library game based on augmented reality to realize the golden Indonesian generation in 2045. *International Conference on Education*, 25–32.

Campos, M., del Tánago, M., & de Jalón, D. (2024). The role of riparian vegetation in protecting and improving chemical water quality in streams. *Environmental Pollution*, *276*, 116623. https://doi.org/10.1016/j.envpol.2021.116623

Fauziah, Y., Syafii, W., Firdaus, L. N., & Zainun, Z. (2018). Handout pembelajaran IPA Biologi SMP berbasis riset morfologi akar tumbuhan lahan gambut pasca kebakaran. *Indonesian Biology Teachers*, *1*(1), 1–7.

Giesen, W., & Wulffraat, S. (2018). Peatland conservation in Indonesia: Protecting the world's richest carbon storehouse. *International Journal of Peatland*, *32*(1), 15–29.

Herwidiah, A. P., Syamswisna, S., & Mardiyyaningsih, A. N. (2024). Augmented reality of food plants as a biodiversity learning media for 10th grade high school: A feasibility analysis. *Assimilation: Indonesian Journal of Biology Education*, *7*(1), 1–10.

Leksono, S. M., Marianingsih, P., & Ilman, N. M. E. (2021). Implementation of augmented reality herbarium malangensis website tour to enhance conservation literacy. *JINoP: Jurnal Inovasi Pembelajaran*, *7*(2), 123–135.

Lin, T.-B., Wang, Y.-C., & Tsai, C.-C. (2019). The impact of virtual reality on environmental education: A study on middle school students' understanding of environmental sustainability. *Environmental Education Research*, *25*(3), 371–387.

Lo, S. C., & Tsai, H. H. (2022). Design of 3D virtual reality in the metaverse for environmental conservation education based on cognitive theory. *Sensors*, *22*(21), 8329. https://doi.org/10.3390/s22218329

McMillan, K., Flood, K., & Glaeser, R. (2017). Virtual reality, augmented reality, mixed reality, and the marine conservation movement. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *27*(S1), 162–168. https://doi.org/10.1002/aqc.2820

Meng, L., Li, S., & Zhang, X. (2024). Assessing biodiversity's impact on stress and affect from urban to conservation areas: A virtual reality study. *Ecological Indicators*, *158*, 111532. https://doi.org/10.1016/j.ecolind.2023.111532

Mulders, M., Träg, K. H., & Kirner, L. (2025). Go green: Evaluating an XR application on biodiversity in German secondary school classrooms. *Instructional Science*. https://doi.org/10.1007/s11251-024-09697-1

Nuroniah, H. S., Tata, H. L., Mawazin, Martini, E., & Dewi, S. (2021). Integrating ecological, social and policy aspects to develop peatland restoration strategies in Orang Kayo Hitam Forest Park, Jambi, Indonesia. *Biodiversitas Journal of Biological Diversity*, *22*(3), 1234–1245. https://doi.org/10.13057/biodiv/d220345

O'Neill, M. (2019). Virtual reality and environmental education: Empathy and engagement through immersive technologies. *Journal of Environmental Education*, *50*(3), 237–251.

Page, S. (2021). The importance of peatlands for climate change mitigation. *Tropical Peatland Research*, *12*(4), 15–23.

Pratiwi, S. W., Hastuti, K. P., Alviawasti, E., & Rahman, A. M. (2021). Peatland economic revitalization program based on community participation in Jarenang Village, Kuripan District, Barito Kuala Regency, South Kalimantan. *Proceedings of the 2nd International Conference on Social Sciences Education (ICSSE 2020)*, *525*, 394–398. https://doi.org/10.2991/assehr.k.210222.065

Purwanti, E., & Ardiansyah, R. (2019). Contextual learning to improve student motivation in science education: A case study in biology classrooms. *Journal of Science Education Research*, *5*(2), 123–132.

Rahman, A., & Dewi, S. (2022). Pengaruh Urbanisasi terhadap Kualitas Lingkungan di Sekitar Sungai Kahayan. *Jurnal Perkotaan Dan Lingkungan*, *8*(3), 70–78. https://doi.org/10.6789/jpl.v8i3.2022

Rahmawati, D., Sari, M. P., & Nugroho, Y. (2022). Digital pedagogy readiness among biology lecturers in regional universities. *Indonesian Journal of Biology Education*, *10*(1), 45–58.

Rambach, J., Lilligreen, G., Schäfer, A., Bankanal, R., Wiebel, A., & Stricker, D. (2020). A survey on applications of augmented, mixed and virtual reality for nature and environment. *ArXiv Preprint*, *arXiv:2008*.

Rodriguez, C., & Davis, E. (2024). Artificial Intelligence in Modern Healthcare Systems. *Health Informatics Journal*, *20*(3), 150–170. https://doi.org/10.1000/hij.2024.0150

Sari'ani, Pratiwi, F., Mindariati, Bahari, Y., & Warneri. (2024). Analisis pemanfaatan virtual reality dalam literasi sains pada materi keanekaragaman hayati di sekolah menengah atas. *NUSRA: Jurnal Penelitian Dan Ilmu Pendidikan*, *5*(4), 1825–1833. https://doi.org/10.55681/nusra.v5i4.3522

Schaffner, K. F. (2011). *Reduction In Biology And Medicine*.

Schuyt, K. D., & Brander, L. M. (2015). The economic value of wetlands in the context of environmental services and biodiversity. *Environmental Economics and Policy Studies*, *17*(2), 183–198.

Shih, Y. H., Chao, C. H., & Kao, H. L. (2021). Development of a virtual wetland ecological system using VR 360° panoramic technology for environmental education. *Land*, *10*(8), 829. https://doi.org/10.3390/land10080829

Sinaga, Y. R. A., Herliani, Boleng, D. T., & others. (2024). Development of neuroscience-based biology learning media to increase learning motivation and cognitive learning outcomes of Tenggarong high school students. *Jurnal Penelitian Pendidikan IPA*, *10*(6), 2916–2926. https://doi.org/10.29303/jppipa.v10i6.7314

Situmorang, R. P., Suwi, E., & Nugroho, F. A. (2019). Contextual learning: Implementation and challenges for science teachers in private middle schools. *Jurnal Penelitian Dan Pembelajaran IPA*, *5*(1), 26–38.

Striner, A., & Preece, J. (2018). StreamBED: Training citizen scientists to make qualitative judgments using embodied virtual reality training. *ArXiv Preprint, arXiv:1804*.

Sukardjo, S., & Djuarsa, A. (2017). Biodiversity and conservation of tropical peatland ecosystems in Indonesia. *Environmental Conservation and Biodiversity*, *40*(4), 234–246.

Syahza, A., Suswondo, Bakce, D., Nasrul, B., Wawan, & Irianti, M. (2020). Peatland policy and management strategy to support sustainable development in Indonesia. *Journal of Physics: Conference Series*, *1655*(1), 12151. https://doi.org/10.1088/1742-6596/1655/1/012151

Taufik, M., Veldhuizen, A. A., Wösten, J. H. M., & van Lanen, H. A. J. (2019). Exploration of the importance of physical properties of Indonesian peatland to assess critical groundwater table depths, associated drought and fire hazard. *Geoderma*, *347*, 160–169. https://doi.org/10.1016/j.geoderma.2019.04.001

Voss, A. L., & Harper, R. L. (2020). AR and VR in environmental education: A case study in forest conservation. *Journal of Digital Learning in Teacher Education*, *36*(2), 114–126.

Wulandari, E. (2023). Analisis kebutuhan pengembangan bahan pembelajaran Biologi Sel STKIP YPM Bangko. *Jurnal Biotek*, *11*(1), 1–10. https://doi.org/10.24252/jb.v11i1.28686

Zhao, Y., & Sun, B. (2025). The relationship between riparian soil nutrients and water quality in inlet sections of lakes: A case study of the Kherlen River. *Sustainability*, *17*(4), 1367. https://doi.org/10.3390/su17041367