



Abstract. *Taiwan's Indigenous tribes mainly reside in remote mountainous areas, where transportation and educational resources are limited. This study developed and evaluated an immersive virtual drone and Cardboard VR system for Indigenous cultural and science education in elementary schools and examined its potential to enhance learning and reduce the digital divide in remote communities. A teaching experiment was conducted to compare the learning outcomes of Indigenous students and their non-Indigenous peers using the VR learning system. The results showed that VR-based instruction significantly improved learning outcomes for students from both ethnic groups. For non-Indigenous students, learning outcomes were also compared with those of conventional instruction using PowerPoint presentations and videos. Non-Indigenous students in the VR-based teaching group outperformed those receiving conventional teaching in learning achievement, and they also reported higher learning motivation and experienced lower cognitive load. Compared with Indigenous students, non-Indigenous students receiving VR-based teaching showed higher learning achievement and technology acceptance, particularly with respect to perceived ease of use, suggesting that prior technological familiarity may affect system usability and learning outcomes. These findings demonstrate that VR technology has the potential to enhance science education and reduce the digital divide between students from diverse ethnic backgrounds. The results also provide valuable insights into broader VR applications in cultural and science educational contexts.*

Keywords: *Indigenous cultural heritage, science education, virtual reality, virtual drones, digital divide*

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DESIGN AND EVALUATION OF AN IMMERSIVE VIRTUAL DRONE AND CARDBOARD VR SYSTEM FOR INDIGENOUS CULTURAL AND SCIENCE EDUCATION IN ELEMENTARY SCHOOLS

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Introduction

Over the past two decades, advancements in information and communication technology (ICT) have driven substantial global growth, establishing it as an important factor in sustainable economic development. ICT plays an important role across different fields, including healthcare, education, and employment. However, the increasing availability of ICT has also resulted in a growing digital divide, which can impede economic development, reduce access to education and job opportunities, limit innovation, and aggravate social and regional inequalities. Consequently, the urban-rural gap has emerged as a major concern in contemporary societies, particularly in the field of education.

Research Problem

Schools in rural areas face persistent challenges, including limited resources and structural educational inequities, which have drawn increasing research attention. (Chen & Liu, 2013). Compared to urban schools, the disparities continue to expand, adversely affecting students' academic outcomes. Such inequalities stem from interrelated economic, health, and sociocultural factors and are often more severe among Indigenous students. These circumstances reflect the need for targeted and culturally responsive educational strategies to better support their learning and academic development (Mao & Chui, 2025).

The Indigenous Education Development Plan (IEDP), launched by the Ministry of Education, Taiwan (2023), identified the specific needs of Indig-



enous students and outlined a series of core objectives to address these issues. The plan promotes a comprehensive approach that emphasizes not only academic achievement but also the integration of science education with Indigenous culture and living environments. Such integration is essential for providing Indigenous students with a well-rounded, practical education tailored to their needs. Science education has become an important means of addressing social inequalities. Its primary goals are to raise awareness of practical issues and foster meaningful behavioral change through scientific inquiry and evidence-based learning. Science education programs emphasizing hands-on experiences and interactions with nature can enhance cognitive and emotional development, fostering lifelong environmental awareness and sustainable behaviors (Ardoin et al., 2020; Buckler & Creech, 2014).

Research Focus

The development and conceptualization of environmental education have been influenced by diverse historical and cultural contexts. The United Nations Educational, Scientific and Cultural Organization (UNESCO, 2015) emphasizes its role in promoting human well-being while protecting the future of global society. Environmental education equips individuals with problem-solving skills, improves awareness of environmental challenges, and promotes responsible behaviors toward environmental protection and sustainability. It fosters the development of abilities and attitudes necessary for individuals to address environmental challenges effectively and promote sustainability. In addition, environmental education is closely related to science education, as it supports scientific observation, ecological literacy, critical thinking, and inquiry-based learning through the exploration of real-world environmental systems and phenomena.

Environmental education encompasses various forms across educational stages, aiming to deepen students' understanding of the environment and its real-world applications. Closely aligned with science education, it fosters knowledge of the natural world and the interconnections between human actions and ecosystems, while developing skills for conservation and sustainability and promoting responsible environmental behaviors (Husin et al., 2025). Grounded in local knowledge, experiences, and values (Niemiec et al., 2016), this approach facilitates meaningful interactions among students, educators, policymakers, researchers, and diverse communities (Toomey et al., 2017). Despite its growing adoption in schools, implementation and overall impact on sustainability often remain limited, indicating the necessity for more robust strategies.

The Curriculum Guidelines of 12-Year Basic Education, issued by Taiwan's Ministry of Education (2014), define the objectives of environmental education for elementary and secondary students. The guidelines include raising awareness of ongoing environmental crises and addressing challenges such as climate change, resource scarcity, endangered species, and social-environmental injustices. The guidelines also encourage students to adopt green and sustainable lifestyles. The importance of integrating environmental education into the learning process is emphasized in elementary education (Sukma et al., 2020). Participation in environmental education programs has been shown to positively influence children's environmental attitudes and knowledge (Duerden & Witt, 2010). Specifically, science education provides an ideal platform for integrating environmental content, fostering awareness, critical thinking, and problem-solving skills.

Virtual Reality and Virtual Drones

In recent years, immersive technologies, including augmented reality (AR) and virtual reality (VR), have become increasingly accessible. These technologies have been applied across a variety of fields, such as special education (Tan et al., 2022), fire evacuation training (Tucker et al., 2018), and music education (Innocenti et al., 2019), with science education being one of the most extensively studied domains (Hamilton et al., 2021). VR provides fully immersive environments that allow precise control over variables that are often difficult to manipulate in traditional contexts, capturing students' attention through interactive experiences. Beyond enhancing motivation, VR enables the simulation of complex or otherwise inaccessible experiments, promoting deeper learning and comprehension. In comparison, AR overlays digital information onto real-world environments, allowing students to engage with virtual elements while remaining situated within authentic physical contexts, thereby supporting experiential and context-rich learning.

From an educational perspective, VR provides substantial educational benefits, particularly in facilitating knowledge transfer across various contexts (Dede et al., 2017). Virtual environments provide realistic experiences, allowing students to engage in scenarios that would be difficult or impossible to replicate in traditional classrooms, such as hazardous situations (Markowitz & Bailenson, 2021). VR supports teachers in guiding students through

interactive learning experiences with three-dimensional (3D) visualization. Markowitz et al. (2018) studied the learning effectiveness of immersive VR for ocean acidification and found that participants demonstrated improved climate science knowledge and more positive attitudes after VR learning activities.

In particular, science education provides an ideal platform for integrating environmental content, fostering scientific observation, ecological literacy, spatial understanding, and problem-solving skills through immersive learning environments. Through VR-based experiences, students can actively explore ecological systems, observe biodiversity and environmental changes, and develop a more contextualized understanding of relationships between organisms, habitats, and human activities. Such experiential learning approaches also support interdisciplinary connections across biology, ecology, geography, and environmental science, enabling abstract science concepts to be visualized and understood in more authentic and engaging contexts.

Through motion capture and haptic feedback, users can experience highly realistic, interactive 3D environments (Martín-Gutiérrez et al., 2017). VR encourages firsthand exploration, stimulates curiosity, and makes learning more interesting and tangible (Dalgarno & Hedberg, 2001). In science education, immersive technologies enhance students' understanding of ecological and sociocultural contexts, providing experiences that foster both environmental awareness and appreciation for cultural heritage. Although advanced VR headsets such as HTC VIVE and Oculus Quest provide exceptional fidelity and engagement, their cost and technical demands limit widespread adoption in under-resourced schools (Parong & Mayer, 2018). As a more affordable option, Cardboard VR delivers immersive experiences using smartphones, which is accessible to classrooms with limited infrastructure (Kavanagh et al., 2017). Therefore, it can help bridge the digital divide by expanding equitable access to immersive learning in rural areas.

Spangenberg et al. (2023) used immersive VR for promoting environmental conservation by simulating the perspective of a tree. Their findings demonstrated that, while multisensory VR did not significantly increase sense of connection to nature, it encouraged active behavior and reflective thinking. Similarly, an immersive sound ecology project (Rousell & Peñaloza-Cañedo, 2022) integrated Indigenous and non-Indigenous perspectives, illustrating how VR can enhance ecological awareness and promote community identity.

Drones, or unmanned aerial vehicles (UAVs), are remotely operated and widely utilized across civilian, commercial, and scientific applications worldwide (Gholami, 2024). In recent years, virtual drones have increasingly been integrated into science education to provide first-person perspectives of landscapes and ecosystems (Wu et al., 2025). By simulating aerial observations, virtual drones allow learners to explore remote or protected areas, such as forests, wetlands, and wildlife habitats, without disrupting natural habitats. This approach enhances spatial understanding, environmental awareness, and contextual learning, fostering problem-solving skills, critical thinking, and active participation in real-world conservation efforts. Studies show that combining virtual drones with immersive technologies improves engagement, motivation, and comprehension of ecological and conservation topics (Tudor et al., 2018; Krupnova et al., 2020).

Learning Theories

Learning motivation is an important factor influencing the use of VR in education. Motivation theories, such as Self-Determination Theory (SDT), emphasize intrinsic and extrinsic factors that drive learners' engagement and persistence (Wang et al., 2024). Immersive VR enhances intrinsic motivation by providing interactive, hands-on exploration, fostering curiosity, and supporting mastery experiences. Extrinsic motivation is also strengthened through gamified elements, feedback, and visible learning progress, which together sustain engagement and promote deeper learning outcomes. Examining how VR influences learning motivation enables educators to design learning experiences that encourage active exploration and support long-term knowledge retention.

Despite its potential in science education, VR-based learning can impose cognitive challenges. Cognitive Load Theory (CLT) posits that learners have a limited working memory capacity, and excessive cognitive demands can impede learning (Sweller, 1988). Cognitive load is generally classified into three types: intrinsic, extraneous, and germane (Paas et al., 2010). Effective VR design aims to reduce extraneous load while enhancing germane load to improve comprehension, engagement, and knowledge retention. In science educational settings, CLT provides a framework for structuring VR experiences to maximize learning efficiency and avoid overloading students, particularly those in resource-limited contexts. Utilizing Cardboard VR for educational presentations falls within the domain of digital tools. Previous research proposes that when these tools effectively minimize cognitive load, they can significantly improve learning outcomes (Hong et al., 2020). However, research suggests that immersive

learning environments can also increase cognitive load, which may reduce learning effectiveness (Frederiksen et al., 2020). Therefore, additional studies are required to examine if VR reduces or intensifies cognitive load.

The Technology Acceptance Model (TAM) complements the above theoretical frameworks by explaining user adoption and engagement with new technologies (Puiu & Udriștioiu, 2024). According to this model, technology acceptance is primarily influenced by perceived usefulness and perceived ease of use. Accordingly, students are more likely to participate effectively and achieve positive learning outcomes when they perceive the VR system as beneficial. Thus, TAM provides a useful framework for evaluating acceptance of VR applications in education and supporting their practical adoption in Indigenous and rural communities.

Research Questions

Although previous studies have demonstrated that VR can improve learning outcomes and motivation, relatively few studies have examined how low-cost immersive technologies can be applied in Indigenous and science education contexts with limited ICT resources. In particular, little attention has been given to how sociocultural background, technological familiarity, and digital access may influence students' cognitive load, learning outcomes, and technology acceptance in VR-based science education. Moreover, most prior VR studies have primarily focused on learning effectiveness, without integrating theoretical perspectives related to learning motivation, cognitive load, and technology acceptance within a unified framework.

The learning activities in this study were closely related to science education. For example, the use of virtual drones supported geographical observation and environmental exploration, while the study of the Purple Crow Butterfly involved concepts related to biology, ecology, and biodiversity. Through these activities, students learned scientific knowledge by observing natural environments, understanding species characteristics, and exploring relationships between organisms and habitats. Therefore, the proposed VR learning system not only supported environmental education but also aligned with the objectives of elementary science education.

Few studies have examined the effectiveness of VR in Indigenous and rural communities, particularly regarding cognitive load, learning motivation, and technology acceptance. The current study explores the potential of Cardboard VR combined with virtual drones to enhance Indigenous culture and science education. Guided by CLT, learning motivation theory, and TAM, this study developed and evaluated an immersive virtual drone and Cardboard VR system and examined its potential to enhance learning outcomes and reduce the digital divide in remote regions. This study specifically addressed the following research questions:

- RQ1: What are the learning outcomes of Indigenous students after participating in the virtual drone and Cardboard VR learning activities?
- RQ2: What are the effects of VR-based versus conventional instruction on learning outcomes, motivation, and cognitive load among non-Indigenous students?
- RQ3: How do learning achievement and cognitive load differ between students from different ethnic backgrounds after using the VR learning system?
- RQ4: What factors influence differences in technology acceptance among students from diverse ethnic backgrounds after using the VR learning system?

This study provides new insights into the existing literature in several ways. It proposes a low-cost immersive learning framework integrating virtual drones with Cardboard VR to support cultural heritage and science education in resource-limited contexts. Unlike many previous VR studies relying on high-end immersive devices, this study demonstrates the feasibility of scalable and economically accessible VR360 technology for rural schools. This study extends VR-based educational research in elementary science education by conducting a comparative analysis of Indigenous and non-Indigenous students, thereby providing insights into how sociocultural context, technological familiarity, and digital access may affect learning. Specifically, this study integrates CLT, SDT, and TAM into a unified analytical framework to interpret learning achievement, motivation, cognitive load, and user acceptance in immersive educational environments. This theoretical integration provides a broader understanding of the mechanisms underlying VR learning experiences beyond general improvements in motivation and achievement. Finally, the findings provide practical implications for designing equitable and culturally responsive immersive learning systems for under-resourced educational environments.

Research Methodology

Virtual Drone System Design

This study employed VR technology to develop a virtual drone and Cardboard VR learning system aimed at enhancing science education in rural areas. The system serves as an immersive learning tool, allowing students to explore the Maolin Purple Butterfly Valley in southern Taiwan, the Rukai people's homeland. Using an Android smartphone and Cardboard headset, students can explore 360° panoramic views of Indigenous heritage sites and natural landscapes, gaining insights into Rukai culture and local environments. The learning activities in this study included butterfly ecology, habitat observation, biodiversity, and environmental exploration using virtual drones, which are closely related to biology, ecology, and geography education.

A high-resolution DJI Mavic drone was used to capture aerial images of the Rukai tribal area for 3D reconstruction. Flight paths were planned in DJI GS Pro and processed using Bentley iTwin Capture Modeler. The surveyed area covered $1,000 \times 500$ m at 100–120 m altitude. A multi-angle nadir–oblique flight pattern with 70–80% overlap was used to enhance reconstruction quality, with additional flights in more complex terrain. Real-time monitoring and battery replacements were performed until full coverage and sufficient imagery were obtained (Figure 1).

Figure 1

Aerial Imagery of Rukai Tribal Village Acquired Using a DJI Mavic Drone



3D Terrain Model Reconstruction

To create visually realistic 3D terrain models from 2D aerial imagery, this study employed a Multi-View Stereo (MVS) and Structure-from-Motion (SfM) reconstruction approach (Lowe, 2004; James & Robson, 2012). Commonly applied in remote sensing and digital heritage reconstruction, this method produces 3D scenes from highly overlapping images without requiring predefined flight trajectories or ground control points. During data collection, aerial images were captured using a rectangular flight pattern with sufficient overlap and multiple viewing perspectives to enhance aerial triangulation and camera pose estimation accuracy (Figure 2).

Figure 2

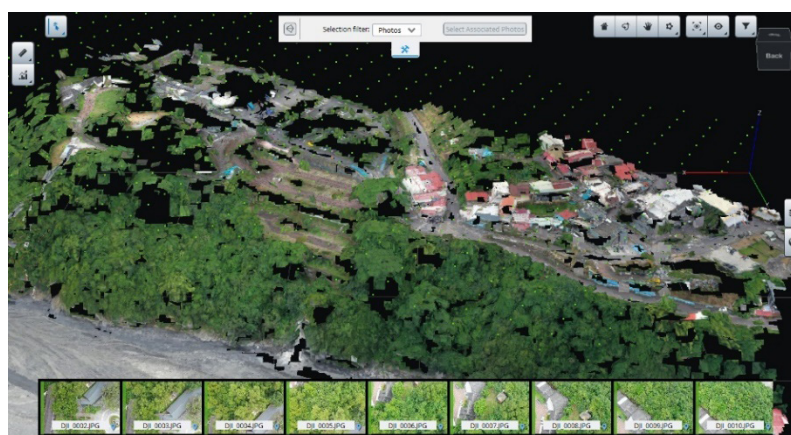
Planned Drone Flight Paths for Aerial Imagery Collection



The reconstruction process began with feature extraction using the Scale-Invariant Feature Transform (SIFT) algorithm, which detects stable key points that remain robust under changes in scale, orientation, and viewing angle. By matching these feature points across overlapping images, aerial triangulation (AT) was performed to estimate camera orientation parameters and generate a sparse 3D point cloud representing the spatial structure of the reconstructed scene (Figure 3).

Figure 3

Sparse 3D Scene Reconstruction Using Aerial Triangulation Results



In the dense reconstruction stage, the MVS approach was employed using estimated camera poses and the sparse point cloud to generate dense depth maps. This approach produced a high-density point cloud capturing terrain structure, building outlines, and vegetation distribution. The point cloud was then meshed and textured with the original images to create a high-resolution and visually realistic 3D terrain model for interactive exploration (Figure 4).

Figure 4

Results of 3D Model Creation and Dense Reconstruction



Virtual Drone Model Design

To facilitate intuitive drone operation, a 3D drone model was developed and integrated into the virtual platform. Optimized for real-time performance on mobile devices, the model was created in Blender 4.0 based on a commercial drone design and included the fuselage, camera, propellers, and landing gear. Symmetry tools were employed to enhance modeling efficiency, while the controller was simplified using basic geometric shapes to resemble a real-world layout (Figure 5).

Figure 5

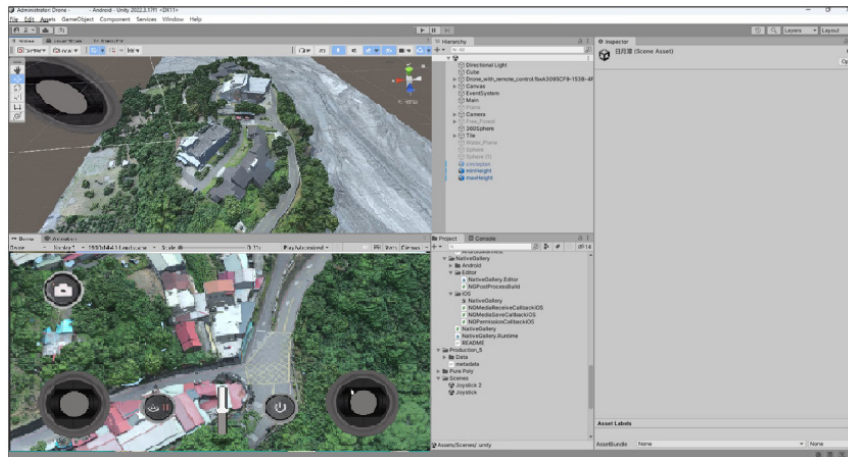
Using Blender 4.0 to Develop the 3D Virtual Drone Model



The drone model was exported in FBX format after applying high-resolution textures and imported into Unity for integration with the reconstructed terrain. Unity enabled interaction logic, UI, and camera control via C# scripting to support an interactive flight simulation. The virtual drone can be controlled according to real-time feedback on position and orientation (Figure 6), with a first-person view activated at higher altitudes to enhance immersion and spatial understanding.

Figure 6

Virtual Drone and Reconstructed Terrain Integration Using Unity Game Engine

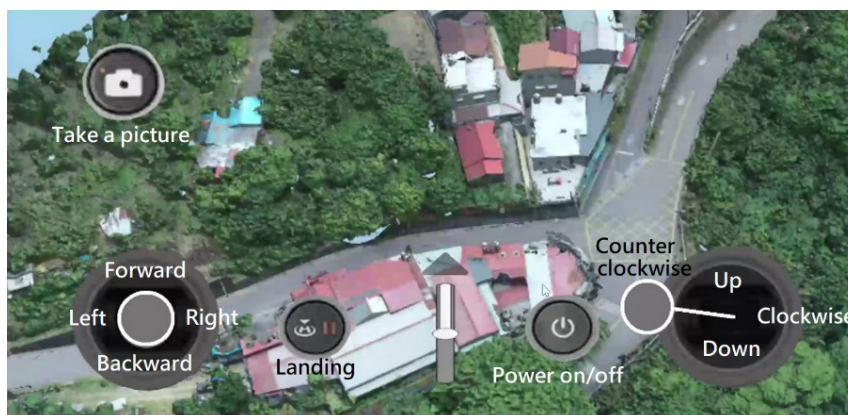


Virtual Drone Navigation

The virtual drone is operated through a dual-joystick control system that enables full spatial navigation. The right joystick is used to adjust orientation and altitude, while the left joystick controls horizontal movement, including forward, backward, and lateral translation, allowing users to rotate the drone for panoramic viewing and ascend or descend vertically. Through this control scheme, users can freely explore the virtual environment, with the camera displaying residential buildings and surrounding vegetation, thereby enhancing landscape visualization and supporting spatial cognition of the Rukai Village and Maolin Purple Butterfly Valley (Figure 7).

Figure 7

Aerial Observation of Rukai Village Using a Virtual Drone



VR360 System Design

The Maolin Purple Butterfly Valley, located on the southern foothills of Taiwan's Central Mountain Range, spans elevations from 230 to 2,700 m above sea level and features a subtropical climate with temperate rainforest ecosystems. Zhuokou Creek flows through this region, supporting its ecological diversity, tourism resources, and distinctive cultural landscape. This area, primarily inhabited by the Rukai people, is recognized as one of Taiwan's well-known tourist destinations. Its mountainous terrain, including cirque landforms and gorge waterfalls, sustains rich biodiversity and provides an ideal habitat for the Purple Crow Butterfly.

To create an immersive learning environment, 360° panoramic images of the valley were captured using a Ricoh Theta camera, ensuring a realistic representation of the natural and cultural landscape while preserving its visual authenticity. The VR360 system incorporates key observation sites and themes, including the Maolin Purple Butterfly Valley, Duona Stone Houses, Zishalishali, Longtou Mountain, and Lover’s Valley (Figure 8).

Figure 8
Observation Points of Maolin Purple Butterfly Valley Shown on Google Maps



Walking along the ecological trails, visitors can enjoy the stunning sight of numerous purple butterflies inhabiting the Maolin Purple Butterfly Valley, a natural wonder that flourishes during migration seasons. The Rukai people have lived here since ancient times, possessing a rich cultural heritage that includes indigenous myths and legends, unique stone houses, towering suspension bridges, exquisite traditional crafts, lively festivals, and flavorful local cuisine. These features, along with breathtaking landscapes, create an unforgettable experience, seamlessly blending nature and culture. All these factors enhance the richness of its cultural tourism, offering visitors a deeper connection to both the natural environment and local traditions (Table 1).

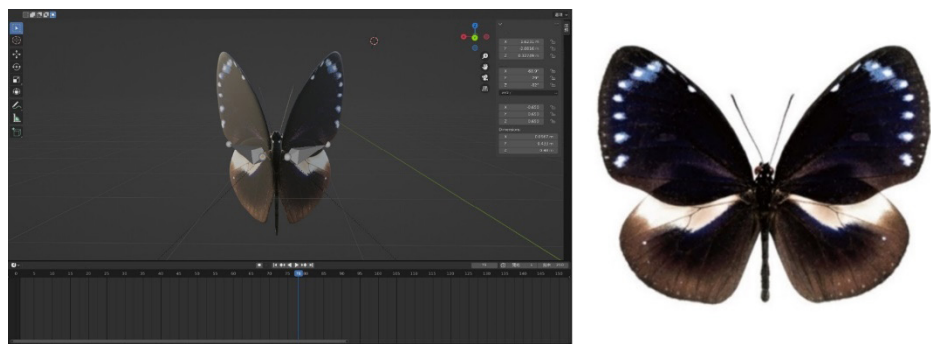
Table 1
Observation Points and Themes in Maolin Purple Butterfly Valley

Location	Theme	Description
Maolin Purple Butterfly Valley	Purple Crow Butterfly	Taiwan is home to four Purple Crow Butterfly species: Striped Blue Crow, Blue-banded King Crow, Double-branded Black Crow, and Dwarf Crow.
	Ecological Environment	Butterflies breed across Taiwan in spring and summer and migrate south in winter, with Maolin as a major overwintering site.
	Natural Landscape	Known as Luomus, beautiful valley in the Rukai language, Maolin hosts millions of migrating butterflies each autumn and winter, offering rich biodiversity and pristine scenery.
Duona Stone Slate House	Slate Materials	Traditional Rukai stone houses are built from locally sourced black-gray slate and shale, shaped into slabs and stacked to form sturdy dwellings.
	Slate Culture	Stone houses reflect Rukai cooperation and social hierarchy; noble houses are ornate, and snake totems indicate a chief's residence, forming the distinctive slate culture.

Location	Theme	Description
Zishalishali	Origin of Place Name	From the Rukai language, meaning “place of abundant wild ginger,” the name reflects the local vegetation identified by early inhabitants.
	Natural Landscape	A forest trail rich in birds, insects, and mammals, and a winter gathering site for Purple Crow Butterflies.
Longtou Mountain	Scenic Area Introduction	A rare enclosed-hill landform surrounded by mountains, featuring streams, cliffs, and a dragon-shaped ridge with dramatic panoramic views.
	Natural Ecology	Zhuokou Creek shapes waterfalls and canyons; the area supports diverse wildlife and soaring eagles, giving rise to its former name, “Eagle Valley.”

In this study, ecological elements such as the Purple Crow Butterfly were modeled using Blender 4.0 to enrich the ecological learning experience (Figure 9). Subsequently, the virtual scenes were created using Unity game engine, integrating interactive and event-triggering functions to enhance user interaction on smartphones. The virtual drone and Cardboard VR learning system converts the Android device into a simple yet highly effective VR tool when paired with Cardboard goggles. This seamless integration provides an accessible and user-friendly approach to exploring and interacting with Indigenous culture and ecological environments.

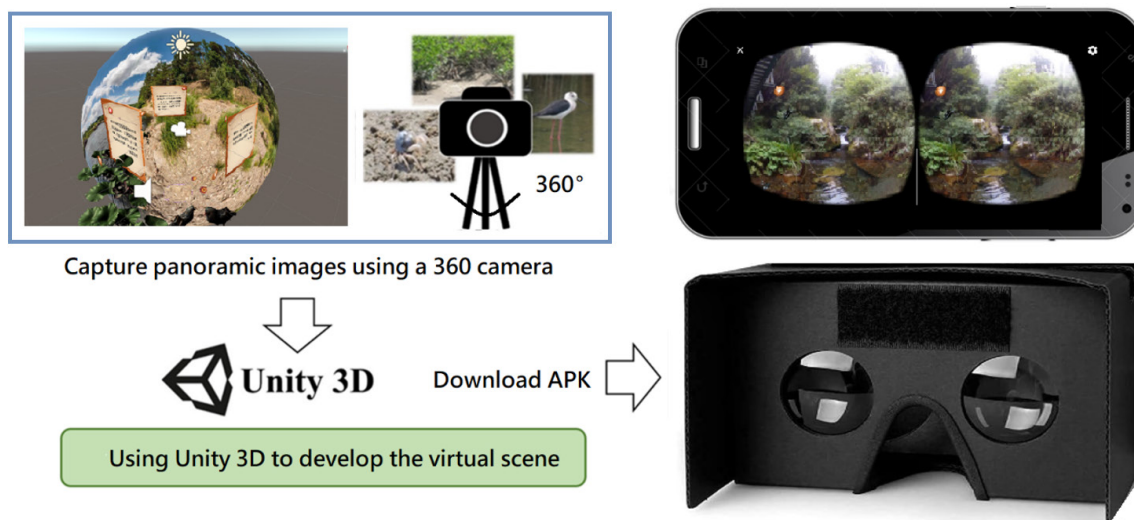
Figure 9
3D Model of Purple Crow Butterfly Created in Blender 4.0



Once the VR360 system was completed, it was installed on Android devices. Students could use a smartphone in combination with Cardboard goggles to enter the virtual scene and explore it interactively. Figure 10 shows the development of visual perception in the Cardboard VR system, which offers advantages such as portability, ease of use, affordability, and the ability to display 3D virtual learning content. Within the virtual scene, users can explore from multiple viewing angles or interact with icons to trigger specific events, such as displaying detailed information, transitioning to other scenes, and playing audio or video. Upon entering a virtual scene, users can engage in exploration guided by task-based learning sheets. The virtual scene includes directional signs to guide users to some other areas, explanations of local wildlife, and information on ecological environments and Rukai Indigenous culture.

Figure 10

Development of Visual Perception Using the Cardboard VR System



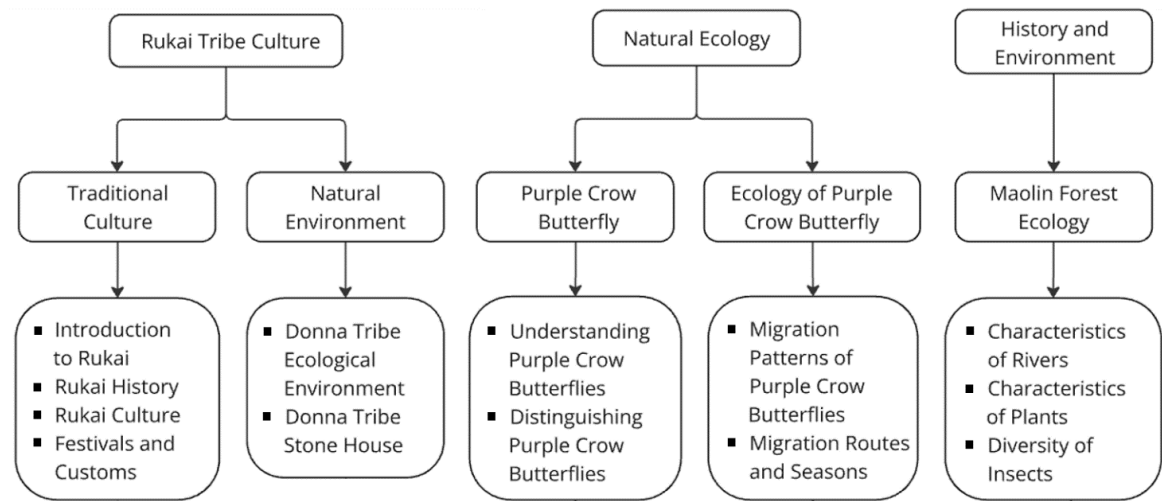
VR360 Learning Content

This study employed an educational design based on the natural landscape of the Maolin National Scenic Area, incorporating its diverse ecology and Indigenous cultural heritage to enhance immersive learning experiences. Maolin is renowned for its pristine streams, dramatic canyons, and rich biodiversity. The region is home to different vegetation, creating a rich habitat for various wildlife species and making it well suited for science education. The Maolin Purple Butterfly Valley serves as a peaceful overwintering ground for the Purple Crow Butterfly, which migrates seasonally across Taiwan and forms large overwintering populations in Maolin, creating a visually stunning ecological display. Its abundant ecological environments, with lush vegetation, flowing streams, and mountainous terrain, provide ideal conditions for wildlife survival and breeding.

Duona Village (Rukai Language: Kunadavan) is located in the Maolin region and serves as a home to the Rukai people. Their traditional lifestyles revolve around hunting, cultivating a deep connection with the mountainous wildlife, and relying on the natural environment for sustenance and resources. This profound connection to the land is a fundamental aspect of the Rukai tribe's cultural values, particularly their commitment to ecological conservation. Their respect for nature and dedication to honoring ecological environments reveal a wisdom grounded in sustainable living. The traditional ecological practices of the Rukai people reflect their profound understanding of the land, emphasizing their ability to coexist harmoniously with nature.

Duona Village consists of several small settlements and is one of the Rukai communities that has preserved its traditional culture. The village reflects an unspoiled natural environment and a rich Indigenous heritage. Exploring Duona Village provides valuable insights into the traditional lifestyle of the Rukai people. Along its streets, visitors encounter significant landmarks, including the Sacrificial Platform, Warrior's Call Platform, and Warrior's Trail. These places preserve traces of the warriors who once protected their homeland and the safety of the Rukai people. In Duona Village, Rukai culture remains an integral part of daily life and the surrounding natural environment. To help students learn about these topics, the Cardboard VR system was divided into three sections (Figure 11): Rukai tribal culture, natural ecology, and local environment. Each section contains different virtual scenes related to the learning content.

Figure 11
Learning Content in the Cardboard VR System



Elementary science curricula often introduce insect-related units, such as *Insect Families*, *Insect World*, and *Butterfly Kingdom*, at the fourth-grade level. The primary teaching objectives emphasize using insects as subjects for observation to examine their physical characteristics, body structures, and movements, as well as to understand their growth and metamorphosis throughout the life cycle. In this study, the *Insect World* unit (Table 2) from elementary science textbooks was referenced to design a lesson focused on the ecology of the Purple Crow Butterfly. Drawing on these learning objectives, the Cardboard VR learning system was employed to create an immersive virtual environment representing the ecological habitat of the Purple Crow Butterfly.

Table 2
Analysis of Learning Content in the Insect World Unit

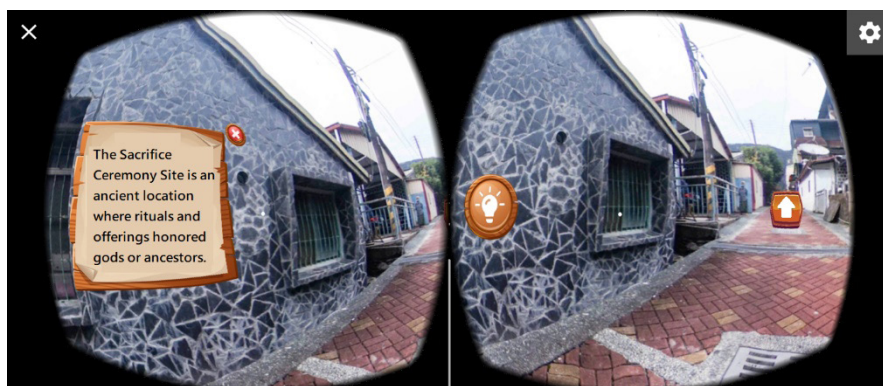
Learning Unit	Teaching Activity	Outlines
Insect World	Understanding insects	• Characteristics of insects
		• Classification of insects
	An insect's life cycle	• Habits of insects
		• Developing a care plan
		• Observing an insect's growth
		• Growth and transformation of insects
	Insects and the environment	• Insects and ecological environments
		• Insect crisis

VR360 System Operation

Users begin the Cardboard VR learning experience by clicking “Start Exploration,” which leads them to a 360° panoramic scene that invites exploration and provides access to designated virtual scenes. Successful progression through the VR360 system requires completing specific tasks within each scene. Upon entering a virtual scene, users can interact with various icons to browse relevant information. For example, in the “Sacrifice Ceremony Site” (Figure 12), a directional sign leads users to the “Head-Hunting Ground” virtual scene.

Figure 12

Lightbulb Icons Used as Triggers to Access Knowledge Points



By gazing at the orange arrow sign, users can smoothly move to the next scene. Additionally, lightbulb icons serve as interactive triggers for accessing important knowledge points. By gazing at the lightbulb icon for a second, users can obtain essential information about the virtual scene. The system also includes a progress bar that updates after each completed task, providing a visual representation of the user's advancement. This feature not only reflects the users' current progress but also reinforces a sense of accomplishment as they move forward.

Butterflies play a vital ecological role as pollinators, herbivores in their larval stage, and prey for carnivores, forming an essential link in the food chain. Their graceful flight also adds vibrancy to natural environments. The VR360 system simulates butterfly flight behavior using 3D visual effects and interactive features, employing advanced computer graphics techniques to provide an immersive and interactive learning experience (Figure 13).

Figure 13

Virtual Butterflies in the Maolin Purple Butterfly Valley

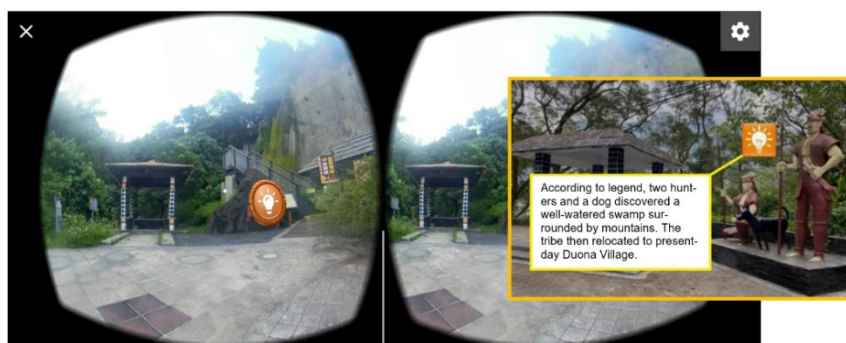


High-resolution images of the Purple Crow Butterfly were captured and applied to a butterfly model. Once the model was completed, the flying motion could be simulated using a C# program, allowing the butterfly to fly freely within the virtual scene. This study employed a state transition model to analyze the butterfly's flight behavior, using a probabilistic function to calculate transition times and flight directions between different states, simulating natural flying motion. To enhance learning in a familiar context for Indigenous students, this study created a virtual butterfly ecological environment based on the Maolin Purple Butterfly Valley.

According to Rukai legend, two hunters, accompanied by their loyal dog, ventured into an unfamiliar area. The dog suddenly stopped at a specific location and refused to proceed, prompting the hunters to carefully examine the surrounding landscape, where they discovered clear mountains, flowing streams, and rich natural resources, making the area a suitable place to settle. After returning to their village, the hunters shared what they had seen with tribal members. Interpreting this as a divine sign, the entire tribe migrated to the area to establish a new home. This story reveals their close connection with nature and symbolizes the tribe's founding, growth, and long-term prosperity, representing a significant aspect of their cultural heritage (Figure 14).

Figure 14

Knowledge Point: Legend of Rukai Tribe's Origins



A quasi-experimental design was employed to examine the effectiveness of the virtual drone and Cardboard VR system compared with conventional instruction using instructional videos and PowerPoint slides in Indigenous cultural and science education. Participants were divided into three groups: an Indigenous experimental group and a non-Indigenous experimental group who learned with the VR system, and a non-Indigenous control group who received conventional instruction. Data collection included pre- and post-tests, a learning motivation scale, a cognitive load scale, and a technology acceptance questionnaire. To maintain consistency across conditions, all groups were instructed by the same teacher using identical learning materials and followed the same teaching schedule, thereby reducing the influence of extraneous variables on the study outcomes.

The study employed a two-phase quasi-experimental design due to contextual constraints in accessing comparable Indigenous and non-Indigenous control groups within the same school setting. Due to the limited sample size of Indigenous students, they participated only in the experimental condition, whereas non-Indigenous students were assigned to both the experimental and control conditions for evaluating the learning effectiveness of the VR system. Although this design allowed meaningful comparisons, it does not fully control for potential cohort or contextual differences. Therefore, causal interpretations should be made cautiously. Future research should adopt a fully balanced experimental design, including Indigenous and non-Indigenous participants across both instructional conditions, to strengthen internal validity and generalizability.

Participants

This study was conducted in two phases. The first phase consisted of an experiment involving 22 Indigenous elementary school students (15 males and 7 females). In this phase, students in the Indigenous experimental group used the VR system as a learning tool to examine its effects on learning achievement, cognitive load, and technology acceptance. The second phase focused on non-Indigenous students, with 60 participants divided into two groups. The experimental group included 30 students (14 males and 16 females) who learned with the VR system (Figure 15). In contrast, the control group, also consisting of 30 students (13 males and 17 females), received conventional instruction with PowerPoint and videos covering the same content.

Figure 15

Indigenous (Left) and Non-Indigenous (Right) Students in Experimental Groups



Instruments

This study employed four research instruments to collect data for evaluating the virtual drone and Cardboard VR system: an achievement test (including pre- and post-tests), two scales measuring learning motivation and cognitive load, and a technology acceptance model (TAM) questionnaire assessing students' perceptions after using the VR learning system. These instruments provided both objective indicators of learning performance and subjective insights into students' motivational states, cognitive demands, and overall system acceptance.

- Achievement Test

To compare learning outcomes across groups before and after intervention, an achievement test aligned with the learning content was developed. To enhance content validity, two science educators and one subject-matter expert reviewed and refined the test items. The final version consisted of 16 multiple-choice questions, each with four answer options (see Appendix). All participants completed the tests before and after the intervention to evaluate the effects of teaching methods and ethnic groups on learning outcomes.

- Learning Motivation Scale

This study utilized a learning motivation scale, adapted from McAuley et al. (1989) with a satisfactory reliability (Cronbach's $\alpha = .83$), to assess motivation differences between two groups. The scale employed a 5-point Likert format, with responses ranging from "strongly disagree" (score = 1) to "strongly agree" (score = 5), where higher scores indicate stronger motivation. It measured three dimensions: interest, effort and pressure, and cognitive ability. Evaluation results showed that higher scores corresponded to increased levels of learning motivation.

- Cognitive Load Scale

To assess cognitive load, this study adapted the scale developed by Thomashow (2001) to compare differences between groups (Cronbach's $\alpha = .84$). The scale consisted of eight items rated on a 5-point Likert scale, ranging from "strongly disagree" (score = 1) to "strongly agree" (score = 5), with lower scores indicating a lighter cognitive load. It was divided into two dimensions: mental load, which assessed the complexity of the learning content, and mental effort, which evaluated the cognitive resources required to process the organization and clarity of the teaching materials.

- Technology Acceptance Questionnaire

The questionnaire evaluated students' acceptance of the virtual drone and Cardboard VR learning system, focusing on its perceived usefulness and ease of use. In this study, the technology acceptance questionnaire developed by Hwang et al. (2013) was adapted and implemented using a 5-point Likert scale based on the TAM framework, with high internal consistency (Cronbach's $\alpha = .93$). Participants rated their agreement from "strongly disagree" (score = 1) to "strongly agree" (score = 5), with higher scores reflecting greater technology acceptance.

Quasi-Experimental Design

Following the instructional intervention, both the Indigenous and non-Indigenous experimental groups completed the TAM questionnaire to evaluate their learning experience and technology acceptance. Additionally, non-Indigenous groups filled out the learning motivation scale, while all three groups completed the cognitive load scale. These measures were used to explore the impacts of various teaching methods on learning motivation and cognitive load. The experimental design captured the diversity of student populations, providing valuable insights into learning achievement, motivation, cognitive load, and technology acceptance across different groups (Table 3). To reduce potential variability between separate experimental phases, both Indigenous and non-Indigenous groups followed the same instructional procedures, learning materials, teaching duration, assessment instruments, and used the VR learning system under the guidance of the same instructor. However, conducting the experiment in separate phases may still have introduced temporal and contextual differences that could not be fully controlled.

Table 3
Research Groups and Interventions in Quasi-Experimental Design

Group	Pre-test	Intervention	Post-test
Indigenous Experimental (n = 22)	X1	T1	Y1, C1, S1
Non-Indigenous Experimental (n = 30)	X1	T1	Y1, C1, M1, S1
Non-Indigenous Control (n = 30)	X1	T2	Y1, C1, M1

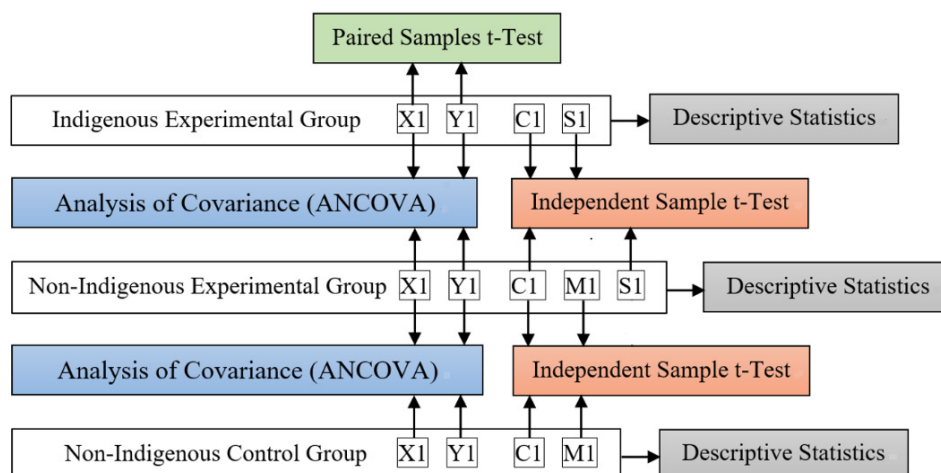
The codes in the above table are explained as follows:

- X1: Pre-test for the three groups
- Y1: Post-test for the three groups
- T1: Interventions for Indigenous and non-Indigenous experimental groups
- T2: Intervention for non-Indigenous control group
- C1: Cognitive load scale for the three groups
- M1: Learning motivation scale for non-Indigenous experimental and control groups
- S1: TAM questionnaire survey for Indigenous and non-Indigenous experimental groups

Statistical Analysis

This study employed four statistical methods described below to assess learning achievement, motivation, cognitive load, and technology acceptance among various groups. Figure 16 illustrates the statistical analysis framework used in this study. Descriptive statistics were first applied to summarize the data collected from the Indigenous experimental group, non-Indigenous experimental group, and non-Indigenous control group. Paired samples t-tests were conducted to examine pre-test and post-test differences within the Indigenous experimental group. ANCOVA was used to compare post-test scores between two groups while controlling for pre-test scores as covariates. Independent samples t-tests were conducted to compare learning motivation, cognitive load, and technology acceptance between students from different ethnic groups and non-Indigenous students receiving different instructional methods. These methods enabled the comparison of within-group learning gains and between-group differences across ethnic and instructional conditions.

Figure 16
Statistical Methods Employed for Analyzing Experimental Data



Research Results

Indigenous Students

The analysis results for Indigenous students include learning achievement, cognitive load, and technology acceptance after using the virtual drone and Cardboard VR learning system.

- Learning Achievement

A paired samples t-test was conducted to evaluate the learning achievement among Indigenous students. The analysis revealed a significant increase in scores from the pre-test ($M = 36.93$) to the post-test ($M = 79.82$), with a mean gain of 42.89 points (Table 4). This difference was significant, $t = 15.32$, $p < .001$, with a large effect size Cohen's $d = 3.27$, indicating statistically significant gains in learning achievement following the VR-based intervention.

Table 4

Paired Samples t-Test Results for Indigenous Group's Learning Achievement

Group	Pre-test	Post-test	Gain	t	p	Cohen's d
Indigenous ($n = 22$)	36.93	79.82	42.89	15.32***	< .001	3.27
$p < .001$ ***						

- Cognitive Load

As shown in Table 5, the overall cognitive load is 1.95 ($SD = 1.10$), indicating a low cognitive load experienced by participants with the VR learning system. In the dimension of mental load, the results suggest that the learning activity imposed a moderate mental load ($M = 2.04$) on students, with some difficulty, effort, and minor frustration involved, but not to an extent that substantially hindered their engagement. Due to the nature of learning tasks and their impacts on cognitive load, the highest score was 2.17 for Question 3, "I found it challenging to complete the questions in this learning activity," which remains within an acceptable range.

Table 5

Cognitive Load for Indigenous Students

Dimension	Evaluation Item	M	SD
Mental Load	1. The material in this learning activity was challenging for me.	1.87	1.07
	2. I needed to exert extensive effort to complete the questions in this activity.	2.08	1.36
	3. I found it challenging to complete the questions in this learning activity.	2.17	1.04
	4. I felt stressed while answering the questions in this learning activity.	2.08	1.25
	5. I did not have sufficient time to finish the questions in this learning activity.	2.04	1.21
Dimensional Cognitive Load (Mental Load)		2.04	1.18
Mental Effort	6. Understanding the instructional methods or content in this learning activity required significant mental effort.	2.12	1.25
	7. Completing the tasks or reaching the learning goals in this activity required significant effort.	1.87	.754
	8. The instructions provided in this activity were hard to understand or follow.	1.62	.90
Dimensional Cognitive Load (Mental Effort)		1.87	.96
Overall Cognitive Load		1.95	1.10

In the dimension of mental effort ($M = 1.87$), the results reveal that understanding the learning content required moderate mental effort, while completing the tasks and achieving the objectives demanded less effort. The instructional content in VR formats was easy to follow and understand. Question 6, "Understanding the instructional methods or content in this learning activity required significant mental effort" received the highest score of 2.12.

This suggests that Indigenous students required a moderate level of mental effort while interacting with the VR learning system. However, despite the low cognitive load scores, offering additional explanations about the learning content could help reduce any potential pressure within the overall teaching model.

- Technology Acceptance

As shown in Table 6, the overall technology acceptance by Indigenous participants after using the VR system is 4.15 ($SD = .89$). Most items received mean scores exceeding 4, indicating an acceptance level between “satisfactory” and “very satisfactory”. This reflects a generally positive learning experience, suggesting a favorable reception of the system. Specifically, the mean score for the dimension “perceived usefulness” was 4.23, reflecting its effectiveness in enhancing student learning. Additionally, the dimension “perceived ease of use” received a mean score of 4.07, suggesting that students found the system user-friendly and supportive of effective learning. However, Question 8, “I learned how to use the system in a short amount of time” scored only 3.82, which was below 4.00. This suggests that some learners may have experienced difficulties due to unfamiliarity with the system and required additional time to understand how to use it.

Table 6
Indigenous Students’ Attitudes Toward Technology Acceptance

Dimension	Evaluation Item	<i>M</i>	<i>SD</i>
Perceived Usefulness	1. The method used in this activity positively supported my learning.	4.45	.78
	2. The system assisted me in gaining new knowledge.	4.41	.93
	3. The features of the system made learning more effective.	4.23	.90
	4. The system allowed me to access helpful information whenever necessary.	4.14	.96
	5. Using this learning approach led to better learning performance for me.	4.18	.88
	6. The learning approach is more effective than traditional learning methods.	4.00	.10
Dimensional Mean (Perceived Usefulness)		4.23	.79
Perceived Ease of Use	7. I was able to operate the learning system without difficulty.	4.05	1.19
	8. I learned how to use the system in a short amount of time.	3.82	1.04
	9. The learning activities within the system were easy to complete.	4.18	.77
	10. I became familiar with the learning system very quickly.	4.23	.77
	11. Using the system during the learning process felt simple and smooth.	4.00	1.10
	12. The interface of the learning system was clear and easy to navigate.	4.14	.82
Dimensional Mean (Perceived Ease of Use)		4.07	1.00
Overall Technology Satisfaction		4.15	.89

Non-Indigenous Students

The analysis results for non-Indigenous students include learning effectiveness, motivation, and cognitive load under various instructional interventions. However, only the experimental group completed the TAM questionnaire to evaluate the technology acceptance of the VR system.

- Learning Achievement

Sixty non-Indigenous students participated in the teaching experiment, evenly divided into an experimental group ($n = 30$) and a control group ($n = 30$). The former had an average pre-test score of 43.13 and an average post-test score of 92.18, whereas the latter recorded an average pre-test score of 46.04 and an average post-test score of 67.50 (Table 7).

Table 7*Descriptive Statistics for Pre-test and Post-test Scores of Non-Indigenous Students*

Group	Pre-test <i>M</i>	Pre-test <i>SD</i>	Post-test <i>M</i>	Post-test <i>SD</i>
Experimental (<i>n</i> = 30)	43.13	11.05	92.18	9.79
Control (<i>n</i> = 30)	46.04	9.78	67.50	10.56

Before performing ANCOVA, the homogeneity of regression slopes was examined by testing the interaction between the covariate (pre-test scores) and the group variable. The interaction effect was not statistically significant ($p > .05$), indicating that the assumption was satisfied. In addition, Levene's test confirmed the homogeneity of variances, $F = 1.49$, $p = .227$. A one-way ANCOVA was conducted to compare post-test scores between non-Indigenous students in the experimental and control groups after controlling for pre-test scores. The ANCOVA results revealed a significant group effect on post-test performance, $F = 88.53$, $p < .001$, with a large effect size $\eta^2 = .608$. Accordingly, students in the experimental group achieved significantly higher learning achievement than those in the control group, suggesting that the VR system was more effective in promoting learning achievement than conventional instruction (see Table 8).

Table 8*Comparison of Learning Effectiveness Between VR-Based and Conventional Instruction*

Source	SS	df	<i>F</i>	<i>p</i>	η^2
Pre-test Score	87.63	1	.84	.362	.015
Group	9209.98	1	88.53***	< .001	.608
Error	5925.638	57			
Total	15223.248	59			

 $p < .001^{***}$

- Cognitive Load

The analysis results of cognitive load (Table 9) showed that non-Indigenous students in the experimental group, using the VR system, had a lower average score ($M = 1.68$, $SD = .76$) compared to the control group ($M = 2.36$, $SD = .66$). An independent samples *t*-test confirmed that this difference was statistically significant, $t = 3.67$, $p < .001$, with a large effect size Cohen's $d = .95$. The findings revealed that the virtual drone and Cardboard VR learning system reduced cognitive load more effectively than conventional instruction.

Table 9*Cognitive Load Comparison Between Non-Indigenous Experimental and Control Groups*

Group	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>	Cohen's <i>d</i>
Experimental (<i>n</i> = 30)	1.68	.76	3.67***	< .001	.95
Control (<i>n</i> = 30)	2.36	.66			

 $p < .001^{***}$

Further analysis of the cognitive load dimensions was conducted using independent samples *t*-tests (Table 10). In the mental load dimension, the experimental group had a lower mean score ($M = 1.71$, $SD = .80$) compared to the control group ($M = 2.36$, $SD = .66$), with the difference being statistically significant, $t = 3.45$, $p = .001$, Cohen's

$d = .89$. In the mental effort dimension, the experimental group scored lower ($M = 1.64$, $SD = .76$) than the control group ($M = 2.36$, $SD = .85$), $t = 3.41$, $p = .001$, Cohen's $d = .88$. The results suggest that the VR system effectively reduced both mental load and mental effort, yielding lower cognitive load than conventional instruction in the context of Indigenous culture and elementary science education.

Table 10

Comparison of Cognitive Load Dimensions Using Independent Samples t-Tests

Dimension	Group	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>	<i>p</i> (Bonferroni)	Cohen's <i>d</i>
Mental Load	Experimental ($n = 30$)	1.71	.80	3.45**	.001	.002	.89
	Control ($n = 30$)	2.36	.66				
Mental Effort	Experimental Group ($n = 30$)	1.64	.76	3.41**	.001	.002	.88
	Control Group ($n = 30$)	2.36	.85				

$p < .01^{**}$

- Learning Motivation

The experimental group had a higher average score ($M = 4.25$) than the control group ($M = 3.87$), indicating higher learning motivation (Table 11). An independent samples t -test revealed a significant difference across groups ($p = .03$) with a medium effect size Cohen's $d = .57$, showing a notable disparity in motivation following the learning experience. Non-Indigenous participants in the experimental group, using the VR system, reported significantly higher learning motivation than those receiving conventional instruction, suggesting that the virtual drone and Cardboard VR learning system effectively enhanced non-Indigenous students' learning motivation.

Table 11

Comparison of Learning Motivation Using Independent Samples t-Tests

Group	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>	Cohen's <i>d</i>
Experimental ($n = 30$)	4.25	.64	2.22*	.03	.57
Control ($n = 30$)	3.87	.68			

$p < .05^*$

Table 12 presents the mean scores and standard deviations of learning motivation among non-Indigenous groups, with Questions 5, 8, 9, 14, and 15 reverse-coded. The results assessed multiple dimensions of engagement and self-perception in learning activities, including effort investment, perceived importance of success, level of relaxation, perceived proficiency, satisfaction with performance, and confidence in mastering the learning approach. In the study, the experimental group exhibited higher engagement with the VR teaching model, with two-thirds of the questions scoring above 4. Participants valued success, invested considerable effort, and generally perceived themselves as proficient and satisfied with their performance. In contrast, only one-third of the questions scored above 4 in the control group, which received conventional instruction, suggesting that the VR-based teaching model may more effectively enhance student engagement.

Table 12*Learning Motivation Results for Non-Indigenous Experimental and Control Groups*

Question	Experimental (n = 30)		Control (n = 30)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
1. I am fully engaged in this learning activity.	4.38	.56	3.97	.70
2. I find this learning activity enjoyable.	4.48	.66	4.08	.56
3. I found this learning activity interesting.	4.28	.61	3.87	.72
4. While using this learning approach, I enjoyed the learning experience and remained engaged in the activities.	4.18	.64	3.77	.74
5. This learning activity did not capture my attention.	3.97	.68	3.66	.59
6. I put a lot of effort into completing this learning activity.	4.58	.60	4.08	.70
7. Achieving success in learning was important to me.	4.68	.56	4.18	.68
8. I made no effort to engage in this learning activity.	3.87	.71	3.56	.61
9. Learning through this approach was stressful for me.	3.77	.66	3.45	.77
10. I felt very relaxed while using this learning approach.	4.28	.62	3.97	.53
11. I believed I was proficient at using this learning approach.	4.48	.64	4.08	.74
12. I was satisfied with my learning performance.	4.58	.66	4.18	.76
13. After using this learning approach for some time, I felt confident in my ability to master it.	4.38	.61	3.97	.73
14. This learning approach didn't teach me much.	3.97	.70	3.66	.60
15. This learning approach failed to capture my interest.	3.87	.69	3.56	.78
Overall Learning Motivation	4.25	.64	3.87	.68

- Technology Acceptance

Based on the results in Table 13, most technology acceptance items had mean scores above 4.5, indicating satisfaction levels ranging from satisfactory to very satisfactory. These results reflect that non-Indigenous students had a positive learning experience and responded favorably to the virtual drone and Cardboard VR learning system. In particular, the mean score for perceived usefulness (4.57) demonstrates its strong contribution to enhancing students' learning, while the mean score for perceived ease of use (4.51) suggests good usability and supports effective learning.

Table 13*Non-Indigenous Students' Attitudes Toward Technology Acceptance*

Dimension	Evaluation Item	<i>M</i>	<i>SD</i>
Perceived Usefulness	1. The method used in this activity positively supported my learning.	4.66	.60
	2. The system assisted me in gaining new knowledge.	4.60	.72
	3. The features of the system made learning more effective.	4.60	.67
	4. The system allowed me to access helpful information whenever I needed it.	4.66	.54
	5. Using this learning approach led to better learning performance for me.	4.63	.71
	6. The learning approach was more effective than traditional learning methods.	4.30	.95
Dimensional Satisfaction (Perceived Usefulness)		4.58	.69

Dimension	Evaluation Item	<i>M</i>	<i>SD</i>
Perceived Ease of Use	7. I was able to operate the system without difficulty.	4.60	.72
	8. I learned how to use the system in a short amount of time.	4.36	.85
	9. The learning activities within the system were easy to complete.	4.46	.81
	10. I became familiar with the system very quickly.	4.60	.77
	11. Using the system during the learning process felt simple and smooth.	4.50	.77
	12. The system interface was clear and easy to navigate.	4.56	.77
Dimensional Satisfaction (Perceived Ease of Use)		4.51	.78
Overall Technology Satisfaction		4.54	.73

Comparative Analysis Between Ethnic Groups

The following analysis examines differences in learning achievement, cognitive load, and technology acceptance between ethnic groups using the VR learning system.

- Learning Achievement

Table 14 shows that Indigenous participants obtained an average pre-test score of 36.93 ($SD = 15.18$) and an average post-test score of 79.82 ($SD = 9.35$). In contrast, non-Indigenous participants achieved a pre-test mean of 43.13 ($SD = 11.05$) and a post-test mean of 92.18 ($SD = 9.79$). The mean gains of these two groups reveal that Indigenous students demonstrated smaller improvements ($M = 42.89$) compared to their non-Indigenous peers ($M = 49.05$).

Table 14

Descriptive Analysis of Learning Achievement for Both Experimental Groups

Experimental Group	Pre-test <i>M</i>	Pre-test <i>SD</i>	Post-test <i>M</i>	Post-test <i>SD</i>
Indigenous ($n = 22$)	36.93	15.18	79.82	9.35
Non-Indigenous ($n = 30$)	43.13	11.05	92.18	9.79

Prior to conducting ANCOVA, the homogeneity of regression slopes assumption was tested. The interaction between pre-test scores and group was not significant ($p > .05$), indicating that the assumption was satisfied. Levene's test revealed that the assumption of homogeneity of variances was satisfied, $F = .27$, $p = .609$. A one-way ANCOVA was conducted to examine differences in post-test scores between the two experimental groups while controlling for pre-test scores (Table 15). The ANCOVA results revealed a significant main effect of group on post-test scores, $F = 15.253$, $p < .001$, with a large effect size $\eta^2 = .237$. After adjusting for pre-test scores, the non-Indigenous group demonstrated greater improvement in learning achievement than the Indigenous group. These results suggest that the VR system enhanced learning outcomes for both groups; however, prior VR exposure may have partially contributed to differences in learning performance.

Table 15

Learning Achievement Comparison Between Experimental Groups Using ANCOVA

Source	<i>SS</i>	<i>df</i>	<i>F</i>	<i>p</i>	η^2
Pre-test Score	454.851	1	5.623	.022	.103
Group	908.398	1	15.253***	< .001	.237
Error	4128.205	49			
Total	403720.500	51			

$p < .001^{***}$



- Cognitive Load

Table 16 presents the cognitive load results for Indigenous and non-Indigenous students in the experimental groups. Indigenous students reported an average overall cognitive load of 1.95 ($SD = 1.10$), whereas non-Indigenous students reported a slightly lower average of 1.68 ($SD = .76$). An independent samples t-test revealed that this difference was not statistically significant, $t = .88$, $p = .395$, with a small effect size Cohen's $d = .24$. These results suggest that the VR learning activities imposed comparable cognitive demands on both groups, revealing that the system imposed a similar level of cognitive load across students' ethnic backgrounds.

Table 16

Cognitive Load Comparison Between Experimental Groups Using Independent Samples t-Tests

Group	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>	Cohen's <i>d</i>
Indigenous ($n = 22$)	1.95	1.10	.88	.395	.24
Non-Indigenous ($n = 30$)	1.68	.76			

An analysis of the cognitive load dimensions—mental load and mental effort—revealed no significant differences across the two ethnic groups (Table 17). For mental load, the Indigenous group reported a mean of 2.04 ($SD = 1.18$), whereas the non-Indigenous group reported a mean of 1.71 ($SD = .80$), $t = .52$, $p = .606$, Cohen's $d = .33$. For mental effort, the Indigenous group obtained a mean of 1.87 ($SD = .96$) and the non-Indigenous group obtained a mean of 1.64 ($SD = .76$), $t = 1.05$, $p = .300$, Cohen's $d = .27$. These results reveal that both groups experienced comparable cognitive demands while using the virtual drone and Cardboard VR learning system.

Table 17

Mental Load and Mental Effort Comparison for Ethnic Groups using Independent Samples t-Tests

Dimension	Experimental Group	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>	<i>p</i> (Bonferroni)	Cohen's <i>d</i>
Mental Load	Indigenous ($n = 22$)	2.04	1.18	.52	.606	1.000	.33
	Non-Indigenous ($n = 30$)	1.71	.80				
Mental Effort	Indigenous ($n = 22$)	1.87	.96	1.05	.300	.600	.27
	Non-Indigenous ($n = 30$)	1.64	.76				

- Technology Acceptance

Table 18 shows that the Indigenous group obtained a mean score of 4.15 ($SD = .89$), compared with 4.27 ($SD = .59$) for the non-Indigenous group. An independent samples t-test was conducted, and the results revealed no significant difference between the two groups ($p = .067$). However, the medium effect size Cohen's $d = .53$ suggests that non-Indigenous students reported moderately higher satisfaction with the VR learning system than Indigenous students.

Table 18

Technology Acceptance Comparison for Ethnic Groups Using Independent Samples t-Tests

Experimental Group	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>	Cohen's <i>d</i>
Indigenous ($n = 22$)	4.15	.89	1.82	.067	.53
Non-Indigenous ($n = 30$)	4.27	.59			

Table 19 shows the technology acceptance scores for Indigenous and non-Indigenous students. For perceived usefulness, the Indigenous group reported a mean of 4.23 ($SD = .79$), whereas the non-Indigenous group reported a mean of 4.57 ($SD = .69$). An independent samples t-test revealed that the difference was not statistically significant, $t = 1.80, p = .077$, although a medium effect size was observed (Cohen's $d = .46$). In contrast, for perceived ease of use, Indigenous students obtained a mean of 4.07 ($SD = 1.00$), compared to 4.51 ($SD = .78$) among non-Indigenous students. This difference was statistically significant, $t = 2.47, p = .017$, with a medium effect size Cohen's $d = .49$. These findings suggest that Indigenous students may have experienced marginally more difficulty operating the VR learning system, potentially reflecting differences in prior VR exposure and contributing to comparatively lower technology acceptance.

Table 19
Technology Acceptance Dimensional Comparisons Across Ethnic Groups

Dimension	Group	<i>M</i>	<i>SD</i>	<i>t</i>	<i>p</i>	<i>p</i> (Bonferroni)	Cohen's <i>d</i>
Perceived Usefulness	Indigenous (n = 22)	4.23	.79	1.80	.077	.154	.46
	Non-Indigenous (n = 30)	4.57	.69				
Perceived Ease of Use	Indigenous (n = 22)	4.07	1.00	2.47*	.017	.034	.49
	Non-Indigenous (n = 30)	4.51	.78				

$p < .05^*$

Taken together, the VR system was found to support learning for both Indigenous and non-Indigenous groups. Although non-Indigenous students revealed higher learning achievement and perceived ease of use toward the system, both groups reported low cognitive load and positive technology acceptance. These findings provided further insight into the potential of immersive VR for cultural and science education contexts.

Discussion

This study developed an immersive virtual drone and Cardboard VR system for Indigenous cultural and science education in elementary schools. The virtual drone enables full spatial navigation, and users can freely explore the virtual environment to enhance landscape visualization and support spatial cognition. The Cardboard VR provides an immersive environment simulating the ecological habitat of the Purple Crow Butterfly and Rukai tribal culture. The virtual scene includes directional signs guiding users to different areas, explanations of local wildlife, and information on ecological environments and Indigenous culture. Students can explore the scene from multiple viewing angles or interact with icons to trigger specific events. Using an Android smartphone and Cardboard goggles, users can explore 3D panoramic views of heritage sites and natural landscapes while learning about Indigenous culture and local environments.

This study examined the educational benefits of integrating virtual drones with Cardboard VR in science education. Overall, the results demonstrate the effectiveness of the integrated VR system in improving students' learning outcomes, with greater gains among non-Indigenous students. The results revealed the educational value of VR applications in supporting meaningful and experiential learning. Future instructional design should consider the diverse learning needs of students from different ethnic backgrounds to ensure that the learning tool reflects authentic real-world contexts and promotes sustained motivation and meaningful learning outcomes.

The findings of this study are consistent with previous research, reporting that VR technology may provide interactive and immersive learning experiences, promote sustained motivation, and enhance academic performance. Krupnova et al. (2020) integrated VR into environmental education to present real-time global issues, support problem-solving, and facilitate collaborative solutions. Similarly, Liu et al. (2019) reported that VR-integrated science education effectively enhanced awareness of environmental issues and understanding of related ethical considerations. The present study extends this literature by demonstrating both the educational benefits of low-cost VR systems and their differential effects across elementary student populations.



The findings can also be interpreted through the theories of CLT, SDT, and TAM. From a CLT perspective, the reduced cognitive load observed in the VR-based learning condition suggests that the immersive and three-dimensional visualizations may have reduced cognitive load while supporting meaningful information processing. The results revealed that an effective VR learning system can enhance comprehension without overloading working memory. From the perspective of SDT, the experimental group exhibited higher engagement with the VR learning system, which may be attributed to enhanced intrinsic motivation. The interactive and exploratory nature of the virtual drone and Cardboard VR can support autonomy and competence, thereby strengthening students' willingness to invest effort in learning activities.

From a TAM perspective (Puiu & Udriștioiu, 2024), differences in perceived ease of use between Indigenous and non-Indigenous students emphasize the importance of usability in VR technology adoption. Although perceived usefulness was comparable, Indigenous students reported lower ease-of-use ratings, suggesting that prior technological familiarity may affect acceptance and learning outcomes. Taken together, the findings suggest that lower cognitive load may be associated with greater perceived ease of use, which may in turn support intrinsic motivation and learning outcomes. The results also provide a coherent explanation for the observed instructional effects, showing that the VR system was more effective for non-Indigenous students. These findings emphasize the importance of designing intuitive user interfaces for learners with limited prior VR experience, especially in environments where access to advanced technologies and digital resources may be constrained, such as remote or under-resourced areas.

Compared with prior studies that primarily evaluated VR learning performance in general educational applications, this study focused on low-cost immersive learning within Indigenous and non-Indigenous science education contexts. The integration of virtual drones and Cardboard VR with cultural and science content offers a practical and accessible approach to supporting immersive learning in regions with limited technological infrastructure. Therefore, the novelty of this study lies not only in the use of VR technology itself, but also in its integration of accessibility, sociocultural context, and theoretical interpretation within a unified educational framework.

Previous studies have similarly reported that differences in technology access between urban and rural regions may influence students' readiness for digital technologies and learning performance (Mao & Chui, 2025). In addition, the low cognitive load reported by both groups suggests that the VR learning environment was accessible and easy to follow (Wu et al., 2025). The immersive visual presentation and contextualized learning content may have helped students understand cultural heritage and science concepts without increasing unnecessary cognitive load. These findings suggest the educational potential of using a lower-cost VR learning system in science education, especially in resource-limited communities.

Integrating virtual drones with Cardboard VR offers an affordable approach to immersive education. However, differences across ethnic groups suggest the need for equitable access and culturally responsive instructional design. Addressing gaps in technology familiarity and providing structured guidance may improve the accessibility and effectiveness of VR-based learning. Due to the limited number of Indigenous students, this study did not include a control group receiving conventional instruction; therefore, the findings for Indigenous students should be interpreted as preliminary evidence of improvement rather than as causal effects of the VR intervention.

Although content validity of the assessment instrument in this study was established through expert review to ensure alignment with the targeted constructs, no formal item-level psychometric analyses were conducted in this study. Specifically, item difficulty indices, discrimination indices, and other item response characteristics were not examined. This is due to the study's primary focus on system validation and intervention effectiveness rather than scale development or refinement. As a result, the measurement properties of individual items were not fully characterized, which may limit the detail of evidence on item performance. Future work should incorporate comprehensive item analysis to further strengthen the psychometric robustness of the instrument and support its broader application in related assessment contexts.

Conclusions and Future Work

This study examined the application of a virtual drone integrated with Cardboard VR for cultural and science education. The system combined Indigenous culture with ecological topics, such as the Purple Crow Butterfly and its habitat, to provide an immersive learning experience. By enabling interactive exploration of tribal villages and natural environments, the system enhanced students' awareness of cultural heritage and ecological

conservation. The findings reveal that the VR system can support science and environmental education by improving learning achievement and learning motivation while maintaining low cognitive load. The findings also suggest that learning resource accessibility and usability play essential roles in affecting VR learning experiences, particularly in Indigenous educational contexts. These insights extend beyond conventional VR evaluations and emphasize the need for equitable and inclusive immersive learning systems.

The experimental results demonstrated significant gains in learning achievement following the VR-based intervention. Overall, technology acceptance was high among participants; however, greater familiarity with VR applications may further enhance user experience and support more effective use of the system. Future refinements should focus on interface optimization to enhance usability and intuitiveness, particularly for Indigenous students with limited exposure to VR learning resources. Among non-Indigenous students, the VR system produced superior learning outcomes compared with conventional approaches, showing the effectiveness of immersive learning systems. Moreover, the VR system reduced cognitive load and increased learning motivation, suggesting its potential to promote sustained engagement in science education.

This study found significant performance differences between Indigenous and non-Indigenous students using the VR learning system, with non-Indigenous students achieving higher learning outcomes. However, no significant differences were observed in cognitive load, suggesting that cultural background did not influence the mental effort required during learning. Although overall technology acceptance was comparable across groups, Indigenous students reported lower perceived ease of use. These findings imply the importance of incorporating additional guidance, scaffolding mechanisms, and user-interface refinements to ensure inclusive and effective use of VR learning systems among students with different levels of technological familiarity.

In spite of its contributions, this study has several limitations that should be acknowledged. First, the Indigenous sample size was small, and no Indigenous control group was included, which may limit the broader applicability of the findings and restrict causal interpretations. Second, the intervention was conducted over a short period, preventing examination of long-term retention effects. Third, although differences in VR technological familiarity were discussed as a possible explanatory factor, prior ICT exposure was not measured. Future studies should employ larger and more balanced samples, incorporate longitudinal designs, and include measures of digital literacy to understand how technological readiness moderates the effectiveness of immersive learning.

Future research should conduct systematic cross-cultural investigations to further examine how immersive learning environments function across diverse ethnic and sociocultural contexts. Such studies could clarify how cultural factors, digital access, and prior VR experience influence both technology acceptance and learning outcomes. Continued optimization of interface design remains essential, as improved usability may support better engagement and enhance learning effectiveness. Moreover, promoting educational equity is important, with greater efforts needed to reduce learning gaps in rural regions and improve access to digital tools and VR technology. The integration of advanced technologies such as mixed reality (MR) and extended reality (XR), with culturally responsive pedagogical models, may further enhance interactivity, immersion, and inclusivity in Indigenous cultural preservation and science education.

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References

- Ardoin, N. M., Bowers, A. W., & Gaillard, E. (2020). Environmental education outcomes for conservation: A systematic review. *Biological Conservation*, 241, Article 108224. <https://doi.org/10.1016/j.biocon.2019.108224>
- Buckler, C., & Creech, H. (2014). *Shaping the future we want: UN decade of education for sustainable development*. UNESCO. <https://unesdoc.unesco.org/ark:/48223/pf0000230302>
- Chen, R. S., & Liu, I. F. (2013). Research on the effectiveness of information technology in reducing the rural-urban knowledge divide. *Computers & Education*, 63, 437-445. <https://doi.org/10.1016/j.compedu.2013.01.002>
- Dalgarno, B., & Hedberg, J. (2001). *3D learning environments in tertiary education*. University of Melbourne.
- Dede, C., Jacobson, J., & Richards, J. (2017). Introduction: Virtual, augmented, and mixed realities in education. In C. Dede, J. Jacobson, & J. Richards (Eds.), *Virtual, augmented, and mixed realities in education* (pp. 1-16). Springer. https://doi.org/10.1007/978-981-10-5490-7_1

- Duerden, M. D., & Witt, P. A. (2010). The impact of direct and indirect experiences on the development of environmental knowledge, attitudes, and behavior. *Journal of Environmental Psychology*, 30, 379–392. <https://doi.org/10.1016/j.jenvp.2010.03.007>
- Frederiksen, J. G., Carstensen, S. M. D., Konge, L., Svendsen, M., Nobel-Jørgensen, M., & Andersen, S. A. W. (2020). Cognitive load and performance in immersive virtual reality versus conventional virtual reality simulation training of laparoscopic surgery: A randomized trial. *Surgical Endoscopy*, 34, 1–9. <https://doi.org/10.1007/s00464-019-06887-8>
- Gholami, A. (2024). Exploring drone classifications and applications: A review. *International Journal of Engineering and Geosciences*, 9(3), 418–442. <https://doi.org/10.26833/ijeg.1428724>
- Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computer Education*, 8, 1–32. <https://doi.org/10.1007/s40692-020-00169-2>
- Hong, J.-C., Hwang, M.-Y., Tai, K.-H., Lin, P.-H., & Lin, P.-C. (2020). Learning progress in a Chinese order of stroke game: The effects of intrinsic cognitive load and gameplay interest mediated by flow experience. *Journal of Educational Computing Research*, 58(4), 842–862. <https://doi.org/10.1177/0735633119881471>
- Husin, A., Helmi, H., Nengsih, Y. K., et al. (2025). Environmental education in schools: Sustainability and hope. *Discover Sustainability*, 6, Article 41. <https://doi.org/10.1007/s43621-025-00837-2>
- Hwang, G.-J., Yang, L.-H., & Wang, S.-Y. (2013). A concept map-embedded educational computer game for improving students' learning performance in natural science courses. *Computers & Education*, 69, 121–130. <https://doi.org/10.1016/j.compedu.2013.07.008>
- Innocenti, E. D., Geronazzo, M., Vescovi, D., Nordahl, R., Serafin, S., Ludovico, L. A., & Avanzini, F. (2019). Mobile virtual reality for musical genre learning in primary education. *Computers & Education*, 139, 102–117.
- James, M. R., & Robson, S. (2012). Straightforward reconstruction of 3D surfaces and topography with a camera: Accuracy and geoscience application. *Journal of Geophysical Research: Earth Surface*, 117, F03028. <https://doi.org/10.1029/2011JF002289>
- Kavanagh, S., Luxton-Reilly, A., Wuensche, B., & Plimmer, B. (2017). A systematic review of virtual reality in education. *Themes in Science and Technology Education*, 10, 85–119.
- Krupnova, T., Rakova, O., Lut, A., Yudina, E., Shefer, E., & Bulanova, A. (2020). Virtual reality in environmental education for manufacturing sustainability in Industry 4.0. In *Proceedings of the IEEE Global Smart Industry Conference (GloSIC)* (pp. 87–91). IEEE. <https://doi.org/10.1109/GloSIC50886.2020.9267848>
- Liu, Q., Cheng, Z., & Chen, M. (2019). Effects of environmental education on environmental ethics and literacy based on virtual reality technology. *The Electronic Library*, 37(5), 860–877. <https://doi.org/10.1108/EL-12-2018-0250>
- Lowe, D. G. (2004). Distinctive image features from scale-invariant keypoints. *International Journal of Computer Vision*, 60, 91–110. <https://doi.org/10.1023/B:VISI.0000029664.99615.94>
- Mao, J., & Chui, H. C. (2025). Indigenous education in Taiwan: Policy gaps, community voices, and pathways forward. *Genealogy*, 9, Article 88. <https://doi.org/10.3390/genealogy9030088>
- Markowitz, D. M., & Bailenson, J. N. (2021). Virtual reality and the psychology of climate change. *Current Opinion in Psychology*, 42, 60–65. <https://doi.org/10.1016/j.copsyc.2021.03.009>
- Markowitz, D. M., Laha, R., Perone, B. P., Pea, R. D., & Bailenson, J. N. (2018). Immersive virtual reality field trips facilitate learning about climate change. *Frontiers in Psychology*, 9, 2364. <https://doi.org/10.3389/fpsyg.2018.02364>
- Martin-Gutiérrez, J., Mora, C. E., Añorbe-Díaz, B., & González-Marrero, A. (2017). Virtual technologies trends in education. *Eurasia Journal of Mathematics, Science and Technology Education*, 13, 469–486. <https://doi.org/10.12973/eurasia.2017.00626a>
- McAuley, E., Duncan, T., & Tammen, V. V. (1989). Psychometric properties of the Intrinsic Motivation Inventory in a competitive sport setting. *Research Quarterly for Exercise and Sport*, 60, 48–58. <https://doi.org/10.1080/02701367.1989.10607413>
- Ministry of Education, Taiwan. (2014). *Curriculum guidelines of 12-year basic education*. <https://www.naer.edu.tw/eng/PageSyllabus?fid=148>
- Ministry of Education, Taiwan. (2023). *5-year midterm project on developing Indigenous education (2016–2020): Centered upon Indigenous subjectivity advancement*. <https://english.moe.gov.tw/cp-116-24095-dbed5-1.html>
- Niemiec, R. M., Ardoín, N. M., Wharton, C. B., & Asner, G. P. (2016). Motivating residents to combat invasive species on private lands: Social norms and community reciprocity. *Ecology and Society*, 21, 2.
- Paas, F., Renkl, A., & Sweller, J. (2010). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, 38(1), 1–4. https://doi.org/10.1207/S15326985EP3801_1
- Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of Educational Psychology*, 110, 785–797. <https://doi.org/10.1037/edu0000241>
- Puiu, S., & Udriștioiu, M. T. (2024). The behavioral intention to use virtual reality in schools: A Technology Acceptance Model. *Behavioral Sciences*, 14, 615. <https://doi.org/10.3390/bs14070615>
- Rousell, D., & Peñaloza-Cañedo, A. (2022). Listening for futures along Birrarung Marr: Speculative immersive experience in environmental education. *Australian Journal of Environmental Education*, 38, 431–450. <https://doi.org/10.1017/ae.2022.34>
- Spangenberg, P., Freytag, S.-C., & Geiger, S. M. (2023). Embodying nature in immersive virtual reality: Are multisensory stimuli vital to affect nature connectedness and pro-environmental behaviour? *Computers & Education*, 204, 104964. <https://doi.org/10.1016/j.compedu.2023.104964>
- Sukma, E., Ramadhan, S., & Indriyani, V. (2020). Integration of environmental education in elementary schools. *Journal of Physics: Conference Series*, 1481, 012136. <https://doi.org/10.1088/1742-6596/1481/1/012136>
- Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12, 257–285. https://doi.org/10.1207/s15516709cog1202_4



- Tan, Q. P., Huang, L., Xu, D., Cen, Y., & Cao, Q. (2022). Serious game for VR road crossing in special needs education. *Electronics*, 11, 2568. <https://doi.org/10.3390/electronics11162568>
- Thomashow, M. (2001). *Bringing the biosphere home: Learning to perceive global environmental change*. MIT Press.
- Toomey, A. H., Knight, A. T., & Barlow, J. (2017). Navigating the space between research and implementation in conservation. *Conservation Letters*, 10, 619–625. <https://doi.org/10.1111/conl.12315>
- Tucker, A., Marsh, K., Gifford, T., Lu, X., Luh, P., & Astur, R. (2018). The effects of information and hazard on evacuee behavior in virtual reality. *Fire Safety Journal*, 99, 1–11. <https://doi.org/10.1016/j.firesaf.2018.04.011>
- Tudor, A. D., Minocha, S., Collins, M., & Tilling, S. (2018). Mobile virtual reality for environmental education. *Journal of Virtual Studies*, 9(2), 25–36.
- UNESCO. (2015). *Sustainable development goals*. <https://www.unesco.org/en/sdgs>
- Wang, Y., Wang, H., Wang, S., Wind, S. A., & Gill, C. A. (2024). A systematic review and meta-analysis of self-determination-theory-based interventions in the education context. *Learning and Motivation*, 87, 102015. <https://doi.org/10.1016/j.lmot.2024.102015>
- Wu, P.-Q., Ding, T.-J., Wu, Y.-J., & Tarng, W. (2025). Development of a virtual drone system for exploring natural landscapes and enhancing junior high school students' learning of Indigenous settlement site selection. *Drones*, 9, 742. <https://doi.org/10.3390/drones9110742>

Appendix: Learning Achievement Test

1. How many indigenous tribes are there in Taiwan?
(1) 15 (2) 16 (3) 17 (4) 18
2. Which architectural style is associated with the Rukai tribe?
(1) Stilt houses (2) Longhouses (3) Watchtowers (4) Slate houses
3. Which of the following is an insect?
(1) Spider (2) Butterfly (3) Millipede (4) Earthworm
4. Which of the following is not a characteristic of insects?
(1) Body divided into head, thorax, and abdomen (2) Head with a pair of antennae (3) 6 legs (4) No wings
5. What does “Zishalishali” mean in the Rukai language?
(1) Symbol of bravery (2) Area with many Bauhinia flowers (3) Scary legend (4) Song of victory
6. What is the significance of hanging human heads on trees in the Head-Hunting Ground?
(1) As a mascot (2) Feeding animals (3) Declaring the warrior's sovereignty (4) Consoling the deceased
7. What was the original name of Maolin Purple Butterfly Valley?
(1) Lumusu (2) Dragon Ball (3) Mini Great Wall (4) Lover's Valley
8. What is the feeding habit of butterflies?
(1) Herbivorous (2) Carnivorous (3) Scavengers (4) Omnivorous
9. Which river does Duona Village span?
(1) Jhuokou River (2) Jhuoshuei River (3) Siougu-luan River (4) Da-an River
10. Which species of butterfly is depicted in the following picture?
(1) Small Purple Crow (2) Common Bluebottle (3) Striped Blue Crow (4) Great Eggfly
11. Which species of butterfly is depicted in the following picture?
(1) Small Purple Crow (2) Common Bluebottle (3) Striped Blue Crow (4) Great Eggfly
12. Which species of butterfly is depicted in the following picture?
(1) Small Purple Crow (2) Common Bluebottle (3) Striped Blue Crow (4) Great Eggfly



13. Which animal symbolizes the Rukai tribe?
(1) Lion (2) Eagle (3) Butterfly (4) Snake
14. What is the sacred and precious item of the Rukai tribe?
(1) Paigasan (2) Ceramic pot (3) Chalice of fire (4) Reed flute
15. How many species of Purple Crow butterflies are there?
(1) 2 (2) 3 (3) 4 (4) 5
16. Which of the following is not a method of movement used by insects?
Flying (2) Gliding (3) Jumping (4) Swimming

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