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Bridging the Gap: Value-Based Strategies in Virtual Reality Integration for Developing SDG 13 and Global Competence

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Abstract: In the wake of intensifying global Extreme Climate Incidents (ECIs), which have particularly noticeable effects on indigenous populations, integrating value-driven education has become a global imperative. While Education for Sustainable Development (ESD) for SDG 13 climate action has been widely adopted in science and engineering curricula, language and culture programs remain underexplored as venues for transformative sustainability learning in Global Competence (GC). Learners in these fields often demonstrate critical literacy and global awareness, but lack the interdisciplinary tools and strategies to translate values into climate-conscious behavior. This study responds to this gap by incorporating virtual reality (VR) into a modified Global Competence Framework (GCF) in an experiment study within intercultural communication courses (N = 303, VR explorative group = 152, control group = 151). A mixed methodological approach was adopted by evaluating pretest–posttest quantitative data of ESD knowledge, attitudes, behaviors, and qualitative data of critical online reflection. The results demonstrate increase localized ESD knowledge in terms of climate, attitudes, and ecological behaviors in both groups in the lived experience of GCF, yet the VR explorative group showed a greater improvement in knowledge and behavior because of their visualization of the 3D rotation of rarely acquired scientific knowledge in monsoonal movement and the local indigenous village reconstruction after destruction. By localizing the Typhoon Morakot tragedy that devastated Shiaolin Village, the intervention provided a culturally specific and interactive context for ESD concepts, enabling interdisciplinary learners to experience climate injustice firsthand with value-based strategies while critically reflecting on global responsibility and sustainable action.

Keywords: education for sustainable development (ESD); extreme climate incidents (ECIs); global competence (GC); global competence framework (GCF); value based; virtual reality (VR)

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1. Introduction

In view of indigenous tribes' disproportionate vulnerability to the climate crisis (5% of the world's population when 15% of the world is poor, with 80% located in climate crisis-prone Asia and Pacific islands [1]), the United Nations' global call to engage in Education for Sustainable Development (ESD) [2,3] has particular relevance. Amid such events as Australian–Californian bushfires, the Indonesian tsunami, African droughts, and Pacific Islands' flooding, extreme climate tragedy has impacted the world [4]. Taiwan also suffered the destruction of an Indigenous village in 2009, and as a non-UN-member, it was desirable to reconstruct it from the ECI deconstruction and take local action to

prevent this from happening again in the future [5]. The destruction of Taiwan's Mayan Shiaolin Village is a classic example of an Extreme Climate Incident (ECI) in need of Global Competence (GC) in terms of cognitive, attitudinal, and behavioral dimensions. The tribe affected by the 2009 Morakot Typhoon refused to excavate 500 Indigenous victims' bodies because of their holistic spirituality and belief in spirit, yet the tribal cultural norms preserved agriculture, mixed rotation of plantations, and hunting in sustainable communities before development [6]. The cultural empathic understanding in GC aligns well with the Education for Sustainable Development (ESD) [7]. When it is important to understand and prevent further ECIs, Taiwan's local indigenous case serves as an ESD for SDG 13 climate action, allowing us to obtain global solutions which allow us to understand ECI tragedies and prevent their reoccurrence.

There is a gap in ESD with regard to SDG 13, which relates to climate actions requiring the development of scientific fields and language and culture fields which will allow the construction of sufficient levels of foundation for sustainable knowledge [8,9]. Previous ESD curricula have focused more on science, ecology-related civil, aerial, and environmental engineering disciplines in higher education [10–12]. SDG 13 has undergone little investigation in English courses, except at the primary and secondary levels.

In the wake of intensifying Extreme Climate Incidents (ECIs), particularly those affecting indigenous populations, integrating cultural value-driven education into sustainability education has become a global imperative [2]. While Education for Sustainable Development (ESD) has been widely adopted in science and engineering curricula [8,9], language and culture programs remain underexplored as venues for transformative sustainability learning. Learners in these fields often demonstrate critical literacy and global awareness, but lack the interdisciplinary tools and strategies to translate their values into climate-conscious behavior [5].

To address the research gap concerning ESD-related knowledge and attitudes, and develop the skills of language students, this study aimed to evaluate the current status of students' ESD and global competence through quantitative analysis. Furthermore, it implemented the Global Competence Framework (GCF) model to examine whether these students could demonstrate measurable progress in both quantitative and qualitative dimensions. This dual-method approach also supports a broader needs analysis for developing ESD-focused curricula for language learners. This study hence responds to this gap by incorporating visually empowering virtual reality (VR) into a modified Global Competence Framework (GCF) [13] to explore what happened, why this ECI happened locally in an indigenous community, how this community reconstructed its sustainable culture and how to prevent such an ECI from happening again—all within an intercultural communication course.

The overall research question is as follows: to what extent did GCF foster language majors' ESD knowledge, attitudes and action in understanding a local ECI by VR interventions?

By localizing the Typhoon Morakot tragedy that devastated Shiaolin Village, the intervention provided a visceral context for ESD concepts, enabling learners to experience climate injustice firsthand, while critically reflecting on global responsibility and sustainable action.

2. Literature Review

2.1. The Extreme Climate Incident (ECI)

Morakot Typhoon, called the 88-Typhoon tragedy in Mandarin, occurred on Father's Day, 2009, and was the deadliest typhoon and ECI to occur in 50 years [14–16]. Some found this tragedy to be the natural consequence of the interplay of the slow speed of the typhoon on landfall with monsoonal flow, and the terrain topography of mountain slopes

of southern Taiwan causing barrier lake eruptions [14,15,17]. However, others viewed it as an issue arising from environmental injustice, and at least partially related to the ecological impact of reservoir trans-basin water diversion and other developments [18,19].

According to Wu (2013) [16], Morakot peaked at 2965 mm (116.73 in.) in 4 days (7–10 August 2009), with severe mudslides, losses of USD 550 million, and the deaths of 700 people, including approximately 500 tribal residents of the single most devastated area: Mayan Tavulon-tribe Shiaolin village [16]. The Indigenous culture reveres the victims without damaging the corpses buried in mudslides, as 180 families were remembered in Shiaolin Village Memorial Museum [20]; the Tavelon tribal indigenous agricultural, hunting, fishing, and festive indigenous outfits are preserved in the Shiaolin *Pingu* (plain indigenous) Cultural Museum [6]. The Indigenous groups grew resilience in terms of cultural, spiritual preservation, and social–economic recovery [14,15,19]. Hence, the current study promotes students' understanding of SDG 13 in the context of this local incident, and encourages sustainable action planning which makes it possible to preserve and promote the indigenous tribal culture.

2.2. ESD, Global Competence, and Values in Action

Education for Sustainable Development (ESD) emphasizes equipping learners not only with knowledge, but also with the values and behaviors necessary to address global crises [3]. In recent years, the OECD's Global Competence Framework (GCF) has offered a structured model to integrate cultural literacy and sustainability awareness into educational systems [13]. However, empirical research suggests that most implementations stop short of enabling learners to act meaningfully on these values [21,22].

Though transformative learning practices, such as VR simulations, have demonstrated the potential to foster empathy and understanding [23], they often fall short of instilling sustained behavioral change without an explicit pedagogical focus on values [24]. Particularly in tertiary language education, a theoretical and practical gap remains with regard to cultivating the affective and behavioral competencies needed for global citizenship [25].

2.3. Gap Between Values of Strategies and VR

While global education initiatives place increasing emphasis on sustainable action, little attention has been paid to how learners internalize values and apply them through strategic, context-responsive behaviors. Current VR-enhanced ESD interventions frequently emphasize cognitive outcomes (understanding biodiversity or climate data), but do not fully address the attitudinal and behavioral competencies necessary to achieve a real-world impact [26,27].

The missing link is a set of value-based strategies: pedagogical tools and curricular models that prioritize empathy, cultural respect, and moral responsibility alongside factual knowledge. These strategies must be culturally embedded, interdisciplinary, and action-oriented, particularly in language classrooms where discourse and critical thinking skills are already foundational [28].

Virtual reality (VR) is a digital approach that allows learners to visualize simulated images, 360-degree videos, and activities in virtual environments, and to explore experiential learning [23,29]. VR could enhance three-dimensional rotation sensory effects, learners' presence, an immersive experience, geographical demonstration, and animated simulations [27,30,31]. There are three advantages which are particularly notable for this study; these are (1) VR-simulating images and videos which provide immersive scaffolding, engagement, and Earth science experiential learning [27]; (2) effective films and 3D storytelling; (3) graphic and rotation knowledge with 3D gamification affordances on Google cardboard on smartphone devices [29]. Through social practice in multiuser virtual social

worlds [32], VR helped enhance global citizenship. Additional VR media affordances urged by Pegrum and Lan (2023) [33] include existing images and videos for geography [34], and tourism for sustainable education [26]. However, technological and communication affordance present limitations: first, the technology requires the use of heavy head-mounted devices with an approximately 5 km battery package [30]; second, there is a lack of in-depth discussion due to the high costs of even a short period of VR usage [26,34]; and lastly, there are concerns associated with potentially abstract and demotivating perception, awareness, and behavior in relation to artificial extreme climate cases [35]. Hence, VR does not guarantee SDG awareness and behavior unless designed in the context of a revised curriculum, teaching appropriate content, and providing meaningful instructional interactions. Thus, this study could maximize existing VR and blend it within intercultural activities in ESD. This study seeks to explore how immersive, localized experiences—such as VR simulations of the destruction of an Indigenous village—can catalyze not only awareness but strategic, values-based action. In doing so, it provides empirical evidence for integrating moral reasoning and affective learning into the ESD–GC nexus.

3. Methods

This study employed a mixed-methods approach. Quantitative data were gathered through pre- and post-intervention surveys modified from those created by UNESCO [36] and the OECD [13], measuring knowledge, attitudes, and self-reported behavior aligned with SDG 13. The study modified a 16-week Intercultural Communication Course, which was a compulsory course in English, Vietnamese, Thai, Indonesian, and Japanese departments offered at a foreign language university in Taiwan (Table 1). Prior to the study, the ICC curriculum had focused on the traditional norm of language and culture theories, exemplified by [37] the traditional language culture of fact, folklore, festival, and food. Participants reported no previous SDG-oriented GC education in Mandarin or English in week 1.

Table 1. Research design of VR interventions.

Timeline	Global Competence Framework	Instructional Interventions
Week 3–9	I. Cognitive Input and Worldviews: Investigating ESD	Environmental lecture Instructor discussing issues reported by the BBC or Taipei Times
Week 10	II. Interacting Culture Heritage-based VR	Experiential VR and AR on SDG 13 and 16 of Tribal Village Memorial Museum
Week 11	II. Interacting science-based VR	VR interventions in the National Science Technology Museum
Week 12	II. e-Cloud asynchronous Discussion	Online Discussion
Week 13–16	III. ESD Action	
Week 17–18	Posttest Critical Reflection	

3.1. Instructional Interventions

The instructional intervention followed a three-stage modified GCF model:

GCF Stage 1. Global Competence Framework merged cognitive input and worldviews from Earth and experimental science experts and guided global news readings, for both groups.

GCF Stage 2. The intervention consisted of two VR simulations: (1) a cultural heritage-based experience in Shiaolin Village Memorial Museum and (2) a science-based exploration in the Science and Technology Museum; followed by e-Cloud asynchronous online interactions with Shiaolin Indigenous persons. For the explorative group, this comprised the following VR experiences to build up the learners' interdisciplinary knowledge. The control group watched relevant news videos.

- (Cultural heritage-based VR): The Indigenous cultural memorial curation, which focuses on the ruins of 2009, showcases an immersive learning environment with a touch-screen, movement-activating panel that allows learners to visualize Indigenous communal life as it was 100 years ago, including night festivals and ethnic outfit try-ons, together with voice-activated presentations of the fishing, hunting, and agricultural community to support harvest and hunting (with emphasis on never taking away newborn and pregnant fishes and animals, so that life can be sustained).
- (Science-based VR simulations): Experiential VR on ECL held in a 360-degree video theater.
- An interactive AI that allows learners to observe the formation of typhoons and change the speeds of monsoonal slope landslide (cause and effect).
- VR which allows learners to select the angle and the time of monsoon landslides and observe their impact via drone footage captured in 15 Indigenous villages in 2008–2018 to allow language students to understand the science-based model.
- VR showing the aftermath of the destruction around the island, with specific areas flooded and houses toppled.
- AI social–cultural selection (allowing the selection of career choices for adults, schooling for children, and medical access for seniors).
- An AI-driven Indigenous community alert system delivered via mobile phone which provides information on water intake and land absorption.
- VR emergency exit equipment and SDG 13 selection of campuses and communities.
- Reflecting on ESD in depth with junior high school teachers, museum staff, and e-Cloud discussion with overseas students to explore their perceptions of the ECI.

GCF Stage 3. Student-led reflection and writing of an advocacy letter, facilitated by the instructor.

3.2. Participants

The participants of both the quantitative and qualitative groups were the same 303 randomly grouped 21–22-year-old students: 152 exploratory group participants and 151 control group students participated in the study. There were 270 Taiwanese students and 33 international students including Japan, Korea, Vietnam, Indonesia, Malaysia, Hong Kong, U.S. and European Union. There were 229 females and 74 males from a Catholic language university in Southern Taiwan, enrolling in six Intercultural Communication courses. Regarding the language specialization, 155 English majors and 148 Asian language majors were equally divided into Thai, Indonesian, and Vietnamese majors. The proportion of valid samples of surveys of both quantitative data and qualitative data, including the online reflection, was 90.19%.

3.3. Instrument

Quantitative data were collected using a modified Global Competence (GC) questionnaire adapted from UNESCO (2022) [36] and OECD (2020) [13] (See the Supplementary Information). It included 26 items answered based on a 1–6 Likert Scale (with 6 as the most strongly agreeing statement) on ESD knowledge on biodiversity constructs ('I know that species may be at high risk of extinction when the average global temperature increases), ocean-level rise ('I am aware of the ocean level rising due to global warming'), ECIs ('I understand what happened to Shiaolin Village in the 2009 Typhoon Morakot), ECI reconstruction ('I know about the village reconstruction in Kaohsiung after the collapse'), climate awareness ('I am aware that SDG 13 cares about the impact of climate change on the poor'), cultural inclusiveness ('I know why Muslim females wear head coverings'), and climate-friendly behavior) with added items related to Shiaolin Village as the lived localized examples of GC. The instrument demonstrated strong reliability (Cronbach's

$\alpha = 0.84$). Qualitative data were aligned with the quantitative constructs and investigated participants' perceptions of ECI, climate awareness, and cultural inclusiveness, given the local ECI reconstruction.

3.4. Data Collection and Analysis

Quantitative data were collected via an online questionnaire administered through the e-Cloud platform at Week 3 (pretest) and Week 18 (posttest). The data were analyzed using descriptive statistics to summarize pretest and posttest values, and inferential statistics were obtained to determine the statistical significance of any differences observed between the experimental (EC) and control (CC) groups. Specifically, Likert scale responses on global citizenship (GC) indicators were analyzed using SPSS Version 29 to assess the effects of virtual reality (VR) interventions.

To supplement the analysis of how language students developed their ESD (Education for Sustainable Development) knowledge and skills, a Thematic-Based Content Analysis [38] outlined by Denzin and Lincoln was conducted following the GCF model and VR interventions in accordance with the qualitative methods.

Qualitative data were gathered during Phases 2 and 3 (Weeks 10 to 16), following VR experiences. These data were collected from asynchronous discussion forums hosted on the e-Cloud platform, where participants posted critical reflections. Participants were organized into groups of five to engage in face-to-face discussions, after which they voluntarily submitted either individual or group responses online via their smartphones during the final 20 min of each session in Phase 2 and Phase 3. Quantitative data analysis was conducted on a corpus of 13,160 words derived from 167 messages. The analysis focused on expressions of value-driven insight related to environmental and cultural identity (ECI), climate awareness, and cultural inclusiveness, particularly in connection with locally reconstructed ECIs and proposed sustainable actions.

This analysis was based on asynchronous online reflections. Thematic categories were identified by the first author and a research assistant, focusing on participants' understanding of ESD in three main areas:

Cognitive understanding—what participants perceived and learned about climate and environmental change issues (e.g., monsoonal shifts, mudslides, landslides, and barrier lake eruptions).

Attitudinal shifts—emotional and empathetic responses, particularly regarding indigenous tribal elders and victims of environmental crises.

Behavioral changes—actions taken by participants, including efforts to preserve Tavulon cultural heritage through language and cultural practices, as well as sustainability-oriented behaviors in daily life and eco-tourism initiatives.

Interrater reliability for the thematic coding reached 85%. Discrepancies in coding were further reviewed and resolved through consultation with domain experts in ecology and sustainability, who served as collaborative advisors. The qualitative analysis focused on how GCF-based instruction—with and without VR support—enabled language majors to address their limited science-based ESD competencies. This was achieved through culturally grounded, rich narrative descriptions that supported a deeper understanding of sustainability concepts. Interrater reliability for the coding process reached a high level of agreement among coders.

Quantitative data and qualitative data were synergized to help examine the effects of progress, if any, for statistical significance between the GC values with or without VR interventions.

4. Results

4.1. ESD Progress on Quantitative Components of Sustainability

ESD knowledge progressed after the application of the GCF model in both EG and CG. Quantitative results indicated significant growth in sustainable knowledge. The exploratory group (EG) who participated in VR interventions exhibited a significant increase in their overall ESD and understanding of local incidents, including reconstruction, while the control group (CG) also progressed, but with less advancement (Table 2).

Table 2. Descriptive statistics of ESD knowledge on sustainable issues.

Sustainable Issue	EG Pretest	EG Posttest	*p*	CG Pretest	CG Posttest	*p*
Biodiversity and Global Warming (Item 6: species extinction; Item 7: ocean-level rise),	5.05	5.24	0.40	5.03	5.19	0.61
SDG 13: Awareness of Impacts on the Poor (Items 10 and 11: awareness of SDG 13)	4.12	4.55	0.13	4.11	4.50	0.14
Consequences of Climate Change (Items 12 and 13: impact of climate change)	3.85	4.55	0.02	3.87	4.51	0.03
Local Extreme Climate Incidents (Item 8: understanding what happened to Shiaolin Village during Typhoon Morako; Item 9: understanding its reconstruction in Kaohsiung after the collapse)	3.84	4.76	0.01	3.86	4.61	0.03
Overall	4.21	4.77	0.03	4.22	4.70	0.05

4.1.1. Improvement in ESD Components Between EG and CG

As shown in Table 2, the EG exhibited a slightly greater overall increase in ESD knowledge (from M = 4.21 to M = 4.77, $p = 0.03$), compared to the control group (from M = 4.22 to M = 4.70, $p = 0.05$). Although both results were statistically significant, the experimental group had a larger effect size, suggesting a more impactful learning experience.

This study explored the impact of virtual reality (VR), enhancing instruction on students' knowledge of key Education for Sustainable Development (ESD) topics. Based on descriptive statistics, both the experimental group (with VR intervention) and the control group demonstrated knowledge gains across all of the assessed sustainability themes. However, the extent and significance of improvement varied noticeably between the two groups.

4.1.2. ECI-Specific Improvements

The most substantial improvements were observed in the domains of *Local Extreme Climate Events* and *Consequences of Climate Change*. In the former, the experimental group showed a mean gain of +0.92 ($p = 0.01$), surpassing the control group's gain of +0.75 ($p = 0.03$). Similarly, in the latter, the experimental group improved by +0.70 ($p = 0.02$), compared to the +0.64 improvement observed in the control group ($p = 0.03$).

For the remaining categories, *Biodiversity and Global Warming and Understanding of SDG 13's Impact on the Poor*, neither group demonstrated a statistically significant improvement due to the ceiling effects. The experimental group's changes were +0.19 ($p = 0.50$) and +0.43 ($p = 0.13$), respectively, indicating only moderate gains. The findings highlight that VR integration in ESD can enhance students' engagement and conceptual under-

standing, particularly regarding complex, context-rich issues such as climate change and localized environmental disasters. While both groups benefited from instructional exposure, the VR experience appears to foster deeper cognitive connections and situational awareness—critical components in sustainability education [39].

These results suggest that immersive technologies may be particularly effective in domains where spatial–temporal visualization and empathy-building are essential. Future curriculum design should continue to explore VR as a pedagogical tool, particularly in underperforming areas like biodiversity and poverty-related SDGs, where students' learning gains are less pronounced.

The most significant improvements were seen in the *Local Extreme Climate Incidents* and *Consequences of Climate Change* categories ($p < 0.05$), highlighting a better understanding of real-world climate impacts. *Biodiversity and Global Warming* and *SDG 13 Awareness on the Poor* showed moderate increases but did not reach statistical significance, suggesting the need for continued emphasis on these areas in future educational efforts. In both items, p values reached a significant level. Perhaps the fact that the ECI occurred in the same town as the research university, 90 min away from the university in one direction, had a significant effect.

Cognitively, students' understanding of ocean-level rise increased from M = 5.10 to M = 5.26, and knowledge of Shiaolin Village's destruction improved from M = 4.16 to M = 4.84. However, knowledge of the reconstruction remained lower initially (M = 3.52) but showed growth post-intervention (M = 4.68) (See Table 3).

Table 3. Descriptive statistics of ESD knowledge on sustainability actions.

Sustainability Action Construct	EG Pretest Mean	EG Posttest Mean	*p* (EG)	CG Pretest Mean	CG Posttest Mean	*p* (CG)
Environmental Resource Conservation and Activities (Items 5, 7, and 9: saving water, electricity, and AC)	4.70	5.23	0.32	4.60	5.19	0.60
Ecological Tableware and Purchasing Behavior (Items 4 and 10: bringing one's own utensils when buying food and buying more costly, ecologically friendly products)	3.55	4.37	0.04	3.57	4.30	0.05
Ecological Petition and Demonstration Participation (Items 6 and 8: signing petitions and signing up for demonstrations)	3.29	3.87	0.05	3.27	3.79	0.06
Average	3.85	4.49	0.14	3.84	4.43	0.30

4.1.3. ESD Actions

EG and CG improved overall ESD action by diverse action measures (Table 3). The *Ecological Tableware and Purchase* category shows a significant improvement from a pretest mean of 3.55 to a posttest mean of 4.37 ($p = 0.04$), indicating responses which align with practices that are more sustainable than their own and their counterparts' daily actions. With VR, the EG showed an increased awareness of *Environmental Resource Conservation and Activities*, such as reducing the amount of electricity they use to power their lights and air conditioning, which was also relevant to lowering their bills; thus, awareness of this strategy was high at the outset with no statistical significance. Lastly, the *Ecological Petition and Demonstration* composite displayed a significant positive shift (from 3.29 to

3.87, $p = 0.05$). Overall, the average score across all composites improved from 3.85 to 4.49. These findings suggest that targeted educational or behavioral interventions may be particularly effective for some sustainability actions (such as tableware choices and petition/demonstration activities), while others may require additional emphasis to drive statistically significant changes.

In terms of participants' ESD actions, the results of the study yielded improvement in four out of seven items related to sustainability and ecological behaviors. The most dramatic progress was observed in relation to turning off the lights or air conditioning in individual private spaces ($p = 0.01$), engaging with environmental petitions ($p = 0.02$), and showing willingness to opt for more costly but ecologically friendly products ($p = 0.03$) (See Table 4).

Table 4. Inferential statistics of sustainability awareness and actions.

	Mean	**t Value**	***p***
Sustainability Awareness	4.73	2.95	0.01
Sustainability Action	3.83		

Given the lack of significant differences between two groups, sustainability awareness and action are a combined inferential representation: a discrepancy was found between ESD knowledge and awareness and sustainable actions ($p = 0.01$) in the posttest, despite there being an improvement over half of the behavior items listed in the study.

Behaviorally, students reported improved adoption of sustainable habits (turning off air conditioning and reducing single-use products), yet civic actions like signing petitions remained limited. The gap between awareness (M = 4.73) and action (M = 3.83) was statistically significant (t = 2.95, $p < 0.01$).

4.2. ESD Perceptions on Qualitative Components of Sustainability

Qualitative data revealed that students' emotional and cognitive engagement deepened through their personal connections to the Shiaolin case and participation in group discussions. Letters sent to national and international organizations demonstrated emerging civic voices. One letter contributed to a policy change related to housing subsidies, indicating potential real-world impact.

While the majority of the participants with language-related backgrounds had a moderately positive understanding of sustainability concepts, they had previously lacked an understanding of the local ECI, and an improvement in their understanding was only made possible through the use of the VR application. They reported a lack of ESD knowledge and theoretical cognitive foundation pertinent to natural science, geometry, and geology. Regarding the first Mayan cultural VR, Participant 37 reflected on learning about the destruction and reconstruction of this ethnically unique culture and passing on an Indigenous song written for those lost in the disaster to a third generation:

> *Before the cultural-based VR experience, I did not believe ECI village destruction would happen in Taiwan. We are such a nation with high technology in weather broadcasts. In the VR of the indigenous memorial museum, and festival dancing of grandmothers, and granddaughters with indigenous songs, I feel so touched by the ways of living, heritage, and the lived stories of the aftermath of daily life. The youths learn how to sing the Tavulon tribal songs and speak the lost language after school life as survivors of Typhoon Morakot.* (Participant 37)

> *After the Shiaolin VR, I knew how powerful Morakot was. . .but as an English major, I found it difficult to know scientific evidence and processes: mudslides, and erupting*

> *barrier lakes for further destruction. The barrier lakes are like artificial dams to destroy everything, and the tribal villagers had to adjust to shelter in a Buddhist temple of lamentation. In response to the Buddhist sheltering and accommodation, some locals preferred betel nuts, indigenous plants and millet, and singing hymns with family and friends.* (Participant 107)

VR and partial AR effectively represented the Tavulon tribal lifestyle by depicting the fishing, hunting, costumes, and night festivals used for ancestral worship, and taught the participants about the Indigenous people's experience of missing their family members who passed away in 2009. This was expressed through collective religious activity, which allowed them to construct a new life pattern with their loved ones in heaven.

Regarding the second VR experience at the National Science and Technology Museum, participants reported the cognitive and affective impact of the ECI:

> *The VR 360 degree theater reminded me that I was 11 year-old boy witnessing helicopters rescuing survivors. Now I am a university student and I wrote to my elementary school principal that all staff and teachers should be educated about sustainability! The village destruction and reconstruction help us understand ESD to prevent the climate disaster and preserve the beauty of mother nature and the Aboriginal community culture with all means.* (Participant 59)

> *Before the Virtual Reality Trip, I used to think the Morakot typhoon was simply a natural disaster. Now I know it is not a simple issue of rainfall on terrain basin. It was a monsoonal flow for the terrain topography of mountain slopes. We as language students could only make sense of what happened, why it happened, and how issues were developed. We had little background knowledge of ecological, and geological models. It is difficult to understand. It is the first time I think SDG 13 has impacted my hometown city Kaohsiung. I knew very little about it before the experience.* (Participant 183)

Participant 83 further detailed the cognitive and emotional impact of 'eruptions of barrier lakes' of massive landslides on how VR helped them to understand what, how, and why ECI occurred:

> *Without the VR, I did not understand the lived dynamics and destruction difference between the terminology of 'landslide' and 'mudslide'. I did not know the meaning of 'barrier lakes' and the deadly impact of their rapid power. I empathize the seniors like my grandmoms raising grandchildren after a tragic accident that killed most.* (Participant 83)

In view of this lack of action, Participants 46 and 53 advocate for more environmental actions in the near future to make an impact:

> *It is most of the time the weakest or least powerful people become the victims of a terrible situation. Weak people suffer for the rest of us all. I think we should stop this from happening again as a global village.* (Participant 46)

> *I am convinced now that we need to do something as a global village, but I am not sure what I can do. I guess if I am invited by Greenpeace volunteers to sign up for an ecological endorsement like protecting sea turtles or anything involving reducing carbon, I would do so next time.*.... (Participant 53)

One participant suggested futuristic eco-tourism could incorporate VR applications (APP):

> *I wonder if future leaders in southern Taiwan can develop eco-tourism that would bring tourists to remember this place without causing CO_2 and ecological destruction. I found the nearby Chishan elementary school and towns developed an App to censor*

> *CO_2 emissions of silver paper money burning, and change our Buddhist temple incense burning by VR worship.* (Participant 242)

> *I think we need to re-think how to promote indigenous eco-tourism in a more sustainable way, and we can encourage green-powered tourist transportation by arriving here not by personal cars or motorcycles. We can use Artificial Intelligence for car parking alert apps, no silver paper burning in Temple worship, and e-bicycles.* (Participant 283)

Both individual and collectivist sustainable ESD action is reflected in these critical reflections. Regarding ECI reconstruction and cultural competence, the next section will illustrate the results.

5. Discussion

Unlike the reports coming from the contexts of Saudi Arabia [40] and Hong Kong [41], this study leveraged GC and ESD to bridge language majors' ESD knowledge, empathy, and action. The study was founded on the cognitive progress of GC and ESD literacy and attitudes (Tables 2 and 3). The intervention aroused cognitive understanding of geographic climate models of 360-degree images, computerized simulations of collapses, and proactive engagement, including renewable energy and a sustainable lifestyle. The pedagogical value of virtual reality (VR) was demonstrated, as it proved to be a cognitively and affectively engaging tool in Education for Sustainable Development (ESD). Statistically significant improvements in sustainability knowledge were observed in both the experimental ($p = 0.03$) and control ($p = 0.05$) groups; however, the VR-integrated instruction produced more substantial learning gains, particularly with regard to context-specific issues such as *Local Extreme Climate Incidents* and *Consequences of Climate Change*. These results support the growing body of evidence that immersive technologies can deepen conceptual understanding by transforming abstract data into embodied experiences [42,43]. Constructivist theory and the principles of Global Competence emphasize sustainable developments, including a) online Buddhist temple worship, b) facilitating eco-tourism that does not involve burning incense and fossil-fueled motorcycles, and c) participating in religious and ancestral practices in sustainable ways. This was evidenced by Participant 282's reflections on implementing futuristic eco-tourism in Cishan by incorporating VR applications (APP), reducing CO_2 emissions by monitoring the burning of incense and ancestral worship paper money, and changing Buddhist temple worship to a VR-based practice to eliminate the burning of incense. Hence, it was determined that successfully implementing sustainable actions in simulated real-world environments may require global mindedness, family culture, and perceived emotional support from parents [41,44,45] in order to purposefully address complex, system-level sustainability issues that traditional methods struggle to communicate effectively.

The learning outcomes which achieved the greatest progress were linked to immersive VR simulations grounded in culturally or geographically proximate cases, evidenced by the Shiaolin Village ECI and disaster reconstruction. Technologically, VR enables an ECI to be theoretically understood in terms of Earth science and ecological models, providing information about how, why, and what kind of ECI occurred. VR helped to develop GC knowledge, awareness, and behaviors in the study, yet there was a gap between cognitive improvement and behavioral outcomes. As evidenced by Participant 83, new systematic sustainable planning is possible, and it is possible to implement Artificial Intelligence and VR solutions through technological innovation. As evidenced by Participant 42, the VR innovations of 'ancestral and local belief worship online' reduce Buddhist temple transportation-induced carbon, incense burning, and long-distance CO_2 emissions. The affective dimension of GC is deepened by localized storytelling and Indigenous perspectives, shaping language and culture majors' emotional responses and enhancing their

empathy. Qualitative reflections revealed a transition from passive knowledge reception to active, meaning-making experiences, echoing the call for emotionally engaging, locally contextualized learning in ESD [46,47]. The simulation allowed students to connect scientific processes—such as barrier lake formation or mudslides—to real human suffering and cultural resilience, which in turn triggered civic expressions like letter-writing and policy advocacy. These findings reinforce the argument that emotional scaffolding and intercultural narratives are vital in mobilizing students from cognitive understanding to civic awareness [10].

Despite clear cognitive and emotional advances, the study identified a persistent disjunction between sustainability awareness and behavioral action (M = 4.73 vs. M = 3.83, $p < 0.01$). Although individual behaviors—such as reduced air conditioning use ($p = 0.01$) and sustainable purchasing ($p = 0.03$)—improved, collective actions like signing ecological petitions lagged behind. This phenomenon reflects a broader pattern in environmental education, where knowledge and empathy do not consistently translate into systemic change [44]. Particularly in contexts like Taiwan, where civic engagement may be culturally restrained, this study highlights the importance of designing pedagogical strategies that explicitly encourage participatory citizenship and long-term behavioral commitment [40]. Embedding guided reflection, sustained project-based learning, and community partnerships may help bridge this critical gap between knowledge and action.

These and other comparative studies have underscored the significance of cultural values in shaping sustainability perspectives and global competencies. For instance, research indicates that ESD and GC levels among language students showed an improvement when compared to results from AI-assisted learning contexts with GC outcomes among Asian Confucian Heritage learners and broader regional contexts recorded up until 2025 [44,45]. A broader cross-national study, assessing GC in 27 societies, revealed that cultural values and parental upbringing strongly influence how individuals perceive sustainability and intercultural understanding [45]. In particular, comparative data from youth populations in Germany, China, and Turkey demonstrated that deeply held family cultural beliefs are foundational for achieving sustainable human relationships—whether between individuals or between humans from different cultures around the planet [41,48]. These insights reinforce the view that cultural values are pivotal to fostering low-carbon, inclusive models of global citizenship. Any explicit interventions that bridge the knowledge–action gap would need to be longer-term, real-world challenges, and collective cultural decision-making scenarios, in order to translate ESD and GC into a form of global sustainability that goes beyond the functionality of VR as a tool for interdisciplinary understanding, facilitating transformative and adequately resourced action.

Finally, the interdisciplinary context of the study offers important implications for language and sustainability education alike. When embedded in intercultural curricula, VR not only facilitated knowledge acquisition in areas like biodiversity and climate science, but also nurtured ethical reflection and social imagination, which are critical components of transformative education [19,43]. The integration of Indigenous stories and cross-cultural perspectives within the VR experience enabled students to connect emotionally and intellectually with issues often perceived as distant or abstract. However, the uneven outcomes in areas such as SDG 13 and biodiversity awareness ($p > 0.13$) suggest that content alone is insufficient. Future research should explore how interdisciplinary, emotionally engaging, and value-based learning environments can be created and optimized to cultivate sustained eco-social behavior and empower learners to become proactive sustainability actors.

6. Conclusions and Implications

The findings of this study highlight a critical gap between knowledge acquisition and behavioral action in the context of ESD (Tables 2–4). The key conclusions can be drawn as follows:

- Despite the effects of combining VR-enhanced learning with traditional, non-VR instructional methods, VR helps improve users' understanding of complex, localized climate phenomena like *Local Extreme Climate Incidents* and *Consequences of Climate Change*. However, a gap persists between awareness (M = 4.73) and action (M = 3.83), revealing a key challenge in transitioning from an intellectual understanding to tangible, real-world action.
- This knowledge–action gap is enhanced by VR models when compared to traditional pedagogies, which may rely on passive and exam-oriented learning in a traditional Asian language context. VR simulations, especially those involving localized disasters or Indigenous narratives, appear to enhance cognitive engagement by making abstract environmental issues more personal and emotionally resonant. However, even within these immersive environments, the translation of this knowledge into sustainable behaviors—such as civic engagement in 'petition, signing up referendum, promoting ESD actions' and long-term lifestyle changes—remains weak in comparison to cognitive gain.
- The study aligns with broader research on global competence models. VR's potential to deepen global awareness (as demonstrated by the significant improvement in local climate understanding) does not necessarily correlate with a comparable improvement in GC for pro-social behavior and environmental activism [40,46].

The implications of these findings suggest that while VR represents a powerful tool for enhancing global competence by providing immersive, situated learning experiences, its value lies not only in the cognitive and emotional engagement it fosters, but also in how such engagement is scaffolded into actionable competencies. A gap remains between the experiential knowledge gained through VR simulations and the development of real-world, proactive global competencies—specifically, the ability to engage in meaningful civic and ecological actions. This gap calls for the integration of behavioral scaffolding—such as action-oriented sustainability projects, community partnerships, and sustained reflection exercises—into VR-based curricula. This is essential for ensuring that students move beyond understanding global issues to actively participating in solutions [10,42,43].

To sum up, this study underscores the efficacy of VR in enhancing awareness and empathy related to sustainability and global competence. The implications are as follows:

- Value-based Pedagogy: Cultural-heritage-based VR intervention in the indigenous Maya tribe was proven to be effective in promoting language majors' sustainability with regard to SDG 13/climate knowledge and awareness (Table 2). Hence, curricula innovation could better integrate value-based empathy and cultural respect, with particular focus on language major students' sustainability development. Values-based educational methods are recommended for future research.
- Global Competence Models: The GC framework (Table 3) enhances emotional engagement with and global awareness of indigenous communities' sustainability and ECI prevention by enabling learners to learn what happened, why it happened, and how to prevent and reconstruct damaged local communities, with a real-life locality and urgency. This would require further costly VR and AR design with technology-enhanced development. Hence, future GC models need to undergo design realignment to facilitate real-world behavior changes, particularly in the realms of SDG 13 pertaining to climate action sustainability and civic engagement.

- Behavioral Scaffolding: In view of gaps in knowledge and action in GC (Table 4), future VR curricula and research could integrate sustained engagement with sustainability practices in the nearby township, in low-carbon Buddhist temples and eco-tourism, community partnerships with the affiliated of the indigenous village, and reflection exercises that guide students toward actionable outcomes in sustainability.

The paper calls for further research into the longitudinal behavioral effects of VR interventions on students' behaviors and attitudes toward sustainability. Additionally, broader curriculum integration across diverse disciplines is recommended to make sustainable action an integral part of the educational experience. However, the real challenge lies in translating this awareness into sustainable action. For VR to effectively contribute to Education for Sustainable Development, it must be part of a comprehensive, value-driven pedagogical strategy that prioritizes cultural sensitivity, and SDG 13 outcomes. The research opens doors for further exploration into how immersive VR reshapes global competence and promotes sustainability across disciplines.

Educational institutions must prioritize interdisciplinary pedagogies that bridge cognitive ESD competence, attitudes, and affective learning. Future research should explore long-term interventions and partnerships that connect students with real-world sustainability efforts. The integration of VR is a powerful start, but to achieve the goals of SDG 13 as global citizens, effective value-based strategies must be fully embedded in ESD curricula.

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