

Empowering Through Knowledge: Exploring Place-based Environmental Education in Louisiana Classrooms Through Virtual Reality

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Abstract—The need for place-based environmental education is paramount to facilitate understanding of complex issues and to support diverse learners in an engaging and authentic pedagogical method. The objective of this design-based research study was to develop, implement, and refine environmental lessons in an interactive virtual reality experience. The Virtual Reality Ecoliteracy Curriculum (VREC) was developed using Unity 3D and tested with middle school students in eighth grade classrooms in Lafayette, Louisiana. The VREC frames learning as a way to explore the theory of place within a virtual environment to inform the design of future educational lessons and learning curricula, thereby facilitating change in learners’ (a) environmental knowledge, (b) engagement, and (c) understanding of how affected communities construct a larger awareness of environmental change. The change was tracked over the course of one school year with two distinct VREC lessons. The participants showed improvement on the quantitative tests and the qualitative results produced overwhelmingly positive responses. This paper details the two VREC lessons and concludes with future implications for improvement of design and implementation of ecoliteracy lessons in virtual reality, including advancing research on assessing and improving learning in immersive virtual environments.

Key words: Educational technology, virtual reality, curriculum development, STEM, ecosystems, place-based education

I. INTRODUCTION

PLACE-BASED education within virtual reality (VR) creates a connectedness to the environment through experiential learning, which increases the significance of meaning and the construction of purpose by giving students a sense of the natural world [1]. Casey Boyd writes, “place is as requisite as the air we breathe, the ground on which we stand, the bodies we have. Nothing we do is unplaced” [2]. Through experiential learning in a VR environment, students are immersed in unique places and are able to construct knowledge and connections that lead

to meaning. Louisiana students gain a unique perspective on the abstract global problem of environmental issues, which are made concrete by the VREC examining local environmental changes. Such examination leads to an immediacy of the concepts of erosion and renewable and non-renewable resources. The wetlands were created over 8,000 years ago and are currently being destroyed faster than they can be rebuilt. From 2004 to 2009, over 70% of these losses occurred in the Gulf of Mexico. Charlie Hammonds, a pilot who lives in Terrebonne Parish, an area with the highest land loss in Louisiana says, “We are living on a dying delta. It’s going to be a fight and I do not think we’re going to win in time” (personal communication, May 27, 2017). Being on the front lines of land loss increases Louisiana’s coastal citizens’ need for understanding their environment. The key to this is to increase adaptive learning in socio-ecological systems across various scales in order to create community resilience. The VREC accomplishes this. It addresses complex problems that the newly developed Next Generation Science Standards (NGSS) [3] support, leading to student development of critical thinking skills and understanding of ecological issues. The VREC aligns with the NGSS focus of a development of core ideas and applying them to make sense of phenomena. The VREC supports a scientific and technology-centered perspective of ecological issues. Some have criticized the NGSS as insufficiently addressing ethics as it applies to sustainability [4], but we propose that the ethical, emotional, and social connection to issues of sustainability can be fostered through direct exposure to personal immersive experiences. The VREC provides an engaging way to learn about the environment with regards to affected communities by allowing students to participate in immersive learning experiences through which they can absorb, understand, and think critically about how human activities and natural phenomena intersect and impact community resiliency and sustainability.

A. Place-based Environmental Education

Place-based education is a pedagogical approach to immerse students in their immediate surroundings and emphasize their lived experiences [5]. Historically, humans were in touch with nature by growing their own food and living off the land. Over time, this has changed, and children spend far more time in

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classrooms and in their homes than they do outside. This has led to an unfamiliarity with their surroundings and what is happening in nature. Students need to first understand what nature is and how they can interact with it. As students are exposed to nature, they gain connections to the environment that lead to a sense of belonging to the natural world [1]. This in turn promotes positive attitudes and behavior that fosters the development of sustainable decisions about the environment. The classroom can promote responsible environmental actions and further sustainability by encouraging students to explore and engage with environmental issues that both teach fundamentals of science and help students develop critical thinking skills. The key to student understanding and development of critical ability is to present environmental issues in the context of real-world, first-hand situations that they experience [6]. First-hand, place-based, immersive experiences are an ideal means to deep learning. As accessibility to virtual and augmented reality technology increases, previous barriers to immersive and engaging environmental experiences are removed and immersive place-based education becomes a reality.

B. Virtual Reality in Education

Virtual environments, such as virtual labs, can provide remote-access to various disciplines of Science, Technology, and Engineering (STE) disciplines and are a cost-efficient way for schools and universities to organize high-quality laboratory work. Virtual laboratory exercises has shown strong potential for learning the basic skills necessary for operating the virtual laboratory system [7]. Virtual reality has great value in situations where exploration of environments and interactions with objects is impossible or inconvenient [8]. Additionally, VR provides a portable solution for training and refinement of skills that reduces costs of bringing in specialized educators, travel time and cost, and risk to the student. As the decay of a skill depends greatly on the degree to which the skill was learned, the higher the acquisition environment (e.g., immersive training), the longer the retention [9]. Information retention will decrease over time if attention is lost due to a lack of interaction with the instructor [10]. Wearing a VR headset with headphones creates auditory and visual exclusion that can focus a viewer and maintain information retention [11]. A meta-analysis of nearly 70 educational VR applications gives evidence that VR-based instruction is an effective means of enhancing learning outcomes [12]. This project utilizes advanced visualization technologies for enhanced student motivation and learning. This can improve education, reaching all fields that can benefit from virtual exploration. This type of application has the potential to broaden access to expert instructors and support more diverse cross-community collaboration between students and experts in a safer educational environment. The methods researched in creating low-cost, VR-based educational applications can be used across any discipline where both field experts and eager-to-learn students exist.

C. Educational Theories in the Creation of Place-based Virtual Reality Environments

The practice of theorizing place-based and VR environments enables researchers to define what students can learn from the

immersive experience. Two traditional theories — experiential learning and constructivism — can be applied to the VREC. The theory of experiential learning offers that lived experiences are tied to how students learn. With the two VREC lessons, the students take their knowledge of what they already know about erosion and renewable and non-renewable resources and apply it to the place-based lessons on Isle de Jean Charles and Delacroix Island in Louisiana. After the lessons, the students have a chance to reflect through surveys and discussion what they have experienced and how the content ties to their lived experiences. In the virtual world, students interact as they turn to look around, being fully immersed within their environment. In the Isle de Jean Charles lesson, the immersion is achieved through 360-degree video, and the interaction is with the place, not with specific objects. For the Delacroix Island lesson, the immersion is created with 360-degree video as well as interactive activities to reinforce learning about renewable and nonrenewable resources. Both VREC lessons allow the students to use prior knowledge taught both in school and comprising their lived experiences, thereby creating connections that are strengthened by understanding. Students also construct their own knowledge and immersing them in place-based virtual environments allows for experiences that could not be replicated in the traditional classroom.

II. METHOD

The study used quantitative and qualitative techniques to gauge the students' experience. The applications would take users between ten and 20 minutes to complete. The learning outcomes were measured by pre-test assessments, post-test assessments, and a questionnaire that provided feedback on the application experience. Each of these would take four to seven minutes a piece, bringing the total average testing time to about 30 minutes per student. Upon completion, students were expected to have a basic understanding of erosion and renewable resources. The topics chosen were in correlation to current topics being taught at the school. The tests administered had between five and six questions worth one point each for pre- and post-tests. All questions were multiple-choice and mainly pertained to general questions regarding erosion and renewable resources. Questions such as, "What is the main cause of erosion?" and "What is a renewable natural resource?" were used. The post-tests were administered immediately after students finished the application. Following the post-test, a user experience questionnaire was administered to students. The questionnaire consisted of nine to 11 questions to judge the user's experience within the application and to gather feedback for improvement. The first set of questions followed a five-point Likert scale where students were asked to rank their experience from one to five ranging from strongly agree (5) to strongly disagree (1) with the statement given. The questions about user experience were developed to gauge the comfort of the VR experience, the controls, the content, the topic, the engagement of the user, motivation level, distractions, attentiveness, concept difficulty, overall satisfaction, and enjoyment of the experience. The next set of questions regarded the user experience level with video games and VR. Finally, three open-ended questions were asked for feedback of positive

and negative aspects of the game and the learning experience.

A. Participants

Thirty middle school participants were involved in the erosion study and one hundred in the renewable resources study. The participants in both studies were male and female middle school students (Table I). All eighth-grade students were invited to participate in the study by both their teacher and the researchers. Institutional Review Board (IRB) documents were approved prior to the study and parent signatures were required before any student could participate.

TABLE I

THE TWO STUDIES PERFORMED WITH ASSOCIATED PARTICIPANTS

Study	Erosion	Renewable resources
Total Participants	30	100
Male	14	58
Female	16	42
Ages	12 to 13	12 to 13

B. Equipment

360-degree photos and videography are taken using ground- and drone-mounted cameras. Several 360-degree cameras are used for content creation, including Ricoh Theta S, 360 Fly, the Panotek 10 camera rig, the GoPro Omni rig, the iZugar Z4XL camera rig, and the YI 360 camera. The immersive applications used a VR headset (Oculus Rift CV1) for display, audio, and wireless-tracked controllers (Oculus Touch) to interact with the environment. Laptops with high-end graphic cards (GTX 1070 or GTX 1080) are used to run the applications.

The Ricoh Theta S camera consists of dual fish-eye lens with HD resolution 1920x1080. The 360 Fly camera has a single fish-eye lens with 4K resolution 2880x2880. YI 360 camera has dual fish-eye lens with 5.7K resolution or 5760x2880. The Panotek camera rig used 10 YI 4K cameras set on 2.7K resolution. The GoPro Omni camera rig used 6 GoPro Hero 4 cameras with 4K or 3840x2160. The iZugar camera rig uses 4 Zcam E1 cameras with MKX22 MFT fisheye lenses with output size at 5400x2700. The Panotek, GoPro Hero, and iZugar camera rigs all require post-processing in the form of stitching and editing to correctly align all the videos. The Kolor software, Autopano Video Pro [14], and Autopano Giga [15], are used to stitch and edit the videos.

C. Software

This application was developed using the game engine, Unity 3D [16], the digital audio editor, Audacity [17], and the 3D computer aided design applications, Blender [18], and Maya [19]. Unity 3D is the game engine that provided the platform for adding models, scripts, animations, and building the application. The Unity 3D plugin Itweens [20], provides an animation system that was used to control the vehicle and player locomotion, and the plugin VRTK (VR tool kit) [21], provided grabbing interactions and controls. Blender and Maya are used for 3D modeling of objects in the scene and applying textures. Audacity was used for recording and editing the narration and sound effects. All of the programming was done using C# in Visual Studio [22], for the Unity 3D game engine.

D. Design of the Learning Environment

Application development steps:

- 360-degree photos and videos are taken on location.
- 3D models are designed, and textures added.
- Models and videos are brought into the Unity 3D game engine where interactive educational content is added.
- The user interface is scripted and voiceover is added.



Fig. 1. Erosion study (left) and renewable resources study (right).

In the erosion application, participants toured Isle de Jean Charles and experienced oral history interviews with five of the Island's inhabitants. Students are immersed in a 360-degree video environment with voice narration, shown in Figure 1 on left, to get a first-hand account of how life on the Island has changed. Teleportation was used, in lieu of game-like controller-based walking, to mitigate dizziness or nausea issues that were reported in previous studies [23]. Once the participants put on the VR headset, the application begins with a help screen explaining the controls, followed by an immersive video introducing participants to the application. During the introduction, participants are greeted by an undergraduate student at the University of Louisiana at Lafayette quad, shown in Figure 2(a), who explains the immersive application and the history of erosion on Isle de Jean Charles.



Fig. 2. Oral Histories in VR on erosion in Isle de Jean Charles application screen shots.

Following the introduction, participants are immersed in five

oral history interviews of local residents, created on what remains of the Island, as shown in Figure 2(b-d). Participants were teleported to the resident's home and heard, first-hand, the experience of losing almost 90% of their homeland over the last 50 years. The participants were immersed in 360-degree pictures and videos and used the tracked remotes for ray-type interaction to replay videos or teleport to the next scene. After the students traveled to each of the five residents' homes, they entered a submersible and were shrunk down to microscopic scale to view water molecules dislodging plant roots over time and watched the Island shrink on a display screen. The microscopic submersible, Figure 2(e-f), showed participants how erosion occurred on the microscopic level while displaying a 2D map of Isle de Jean Charles land slowly disappearing over the last 50 years.

In the renewable resource study, a mix of 360-degree photos and videos along with Computer Aided Design (CAD) modeled environments were used. The participants were situated at large desks, Figure 1, to give them plenty of room to spin around during the application. Once the participants put on the VR headset, the application begins with a help screen explaining the controls then they were teleported to a manned drone, Figure 3(a), with a check list of activities and a selection screen to enable the participant to travel to different areas. Unlike the erosion study, the participant can choose the order of the activities. Giving the user more control for self-exploration enables students to follow their interest and curiosity, providing them a sense of control and empowerment over their own exploration [24]. Each area has a 360-degree video or photo with voiceover information followed by interactive content and a pop-up quiz. The voiceover in the application provided feedback for correct quiz answers and correctly performing activities, such as sorting crabs. This feedback was implemented because it has been shown to have significant impact on learning gains [25]. Pictures of the interactive areas in the virtual environment are shown in Figure 3(b-f).

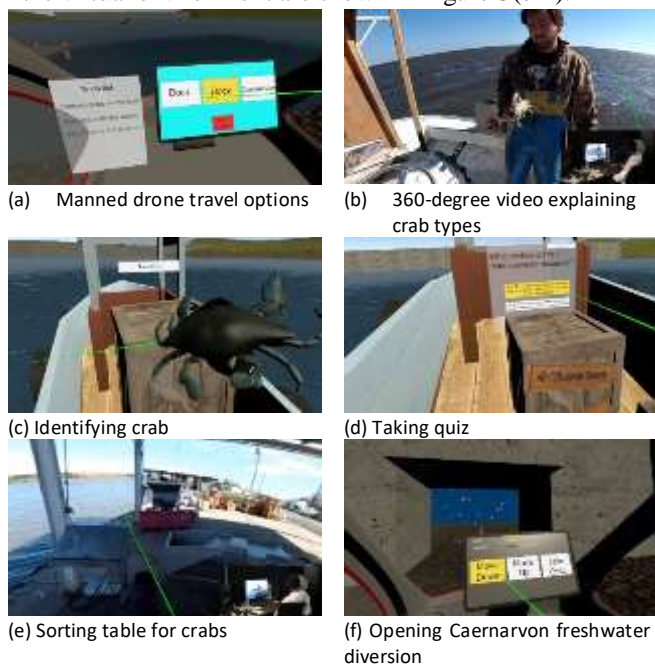


Fig. 3. Delacroix Island renewable resources in virtual reality application screenshots.

In the boat area, shown in Figure 3(b-d), the participants travel to the boat where a 360-degree video shows the crab identification process. The participants then are given different crabs and are asked to identify them and throw small, illegal crabs back into the ocean. This approach to interactive content in the educational application is game-like because games intrinsically stimulate curiosity with the presence of challenges that maintain a person's attention for long periods of time, [26], [27]. Furthermore games have been successful in teaching a certain skills and have shown higher learning gains than virtual world and simulations studies [12], [28]. Following this activity, a pop-up quiz appears where participants are given several options but required to select the correct answer to advance. The quiz serves to reinforce the learning content. After the participants finish the area, they enter the drone again and choose what area to travel to next. In the dock area, participants would sort crabs of various sizes using a measurement tool and various crates. This mimics actual crab sorting at the dock on Delacroix Island, Figure 3(e). In the Caernarvon freshwater diversion area, participants travel in an underwater submersible to adjust the water salinity by opening and closing the freshwater inlet. The mix of 360-degree photos, Figure 3(e), and CAD models, Figure 3(f), provide the participant with photorealism and interactivity while in the environment.

III. RESULTS

A. Testing Results

The average normalized gain has been previously used to measure the average effectiveness of an application in promoting conceptual understanding in a 6,000 student study [29]. The average normalized gain $\langle g \rangle$ is defined as the ratio of the actual average gain (% post - % pre) to the maximum possible average gain (100% - % pre). The normalized gain for each of the studies is shown in Table II.

TABLE II
NORMALIZED GAIN FOR BOTH STUDIES

Application	Erosion	Renewable resources
Normalized Gain	0.02	0.11

The normalized gain for both studies is positive, showing an improvement; however, they are in the low-gain region according to [29]. Although it is a slight amount, the average student has a better understanding of the topic after completing the VR application.

B. Questionnaire Results

As stated in the method section, all students who completed the application were given a questionnaire to complete to assess the user's experience within the application and to gather feedback for improvement. The first set of statements followed the Likert scale where students were asked about the VR experience. The results of the first set of statements, Table III, show strong agreement for both studies.

TABLE III
RESULTS OF AGREE OR STRONGLY AGREE WITH STATEMENTS ABOUT THEIR VR EXPERIENCE

Statements (shortened)	Erosion Study	Renewable resources study
Engaging virtual reality experience	96%	87%
Virtual reality focused attention	89%	92%
Increased comprehension	97%	89%
Reinforced classroom learning	89%	82%
Interesting topic	93%	90%

Table III shows that not only did the participants find the VR experience engaging, but the vast majority (greater than 89%) felt that the application helped focus their attention. Over 90% of the participants were interested in the topics of the VR applications. The topics chosen were in correlation to current topics being taught at the school, and the majority of students (greater than 82%) agreed that the application reinforced classroom learning and increased comprehension.

In the erosion study, 96% of participants agreed that they learned about erosion cause and effects and 67% wanted to learn more. Furthermore, 50% agreed that they intended to talk with peers about what they learned and the VR experience.

In the renewable resources study, participants were asked questions to gauge their experience with video games, VR, and interest level in the application topic. The results are shown in Table IV.

TABLE IV
RENEWABLE RESOURCES STUDY APPLICATION AND EXPERIENCE WITH VIRTUAL REALITY AND VIDEO GAMING STATEMENTS

Statement	% Agree or strongly agree
Effective controls in virtual reality	90%
Effective instruction in virtual reality	83%
Enjoyed the virtual reality experience	82%
Have video game experience	90%
Play video games regularly	65%
Have virtual reality experience	75%

The application consisted of voiceover instruction, animated control diagrams, pop-up quizzes, and required game-like interaction to reinforce learning. In order to improve the application for future studies and to gauge its effectiveness, participants were asked about the controls and instruction in the VR application. Single-button tracked controls were used to minimize issues with remotes, and 90% of participants agreed that they were effective. The instructions were given in a way to minimize assistance needed with completing the application, and 83% of participants agreed this was effective.

Of the 100 participants, 9% strongly disagreed with the playing video games regularly statement, implying that they play seldom or not at all. Of these non-video game playing participants, 89% strongly agreed that the VR experience helped to keep attention focused and the remaining 11% also

agreed with the statement. Furthermore 100% of these non-video gamers agreed or strongly agreed that both the VR experience aided in comprehension and was interesting.

The most common positive feedback on the open-ended question for the two study groups are shown in Table V. Eighty-three percent of students in the erosion study and 86% of the students in the renewable resources study made some comment about the immersiveness or liking the VR experience. Thirty-eight percent of participants commented that the application was informative in the renewable resources study verses only 7% in the erosion study. The interaction was the next most common comment at 21% in the renewable resource study and 7% in the erosion study.

TABLE V
POSITIVE COMMENTS IN BOTH STUDIES

Positive Comments	Erosion	Renewable resources
Like virtual reality	83%	86%
Informative	7%	38%
Interaction	3%	21%
Fun	17%	17%
Interesting	14%	7%

The most common negative feedback comments, shown in Table V, were dizziness and poor graphics in the erosion study. The 360-degree cameras used in this study were the Ricoh Theta S, 360 Fly, and the Panotek rig. For the renewable resources study, the GoPro Hero, iZugar, and YI 360 cameras were used, showing far superior resolution and higher clarity in low light conditions.

TABLE VI
NEGATIVE COMMENTS IN BOTH STUDIES

Negative Comments	Erosion	Renewable resources
Dizzy	7%	2%
Poor graphics	7%	2%
Difficulty	0%	5%
Volume	3%	3%
Eyes adjust	0%	2%

In the renewable resource study, 5% of participants commented on the difficulty of the application. This study required interaction to advance and some participants had issues with the objectives. In the erosion study, the participant's controls were limited to advancing or teleporting to each area where the 360-degree video or animation would play and 0% commented on difficulty of this application.

A summary of the open-ended questions and most common feedback are shown in Table VI. Along with the overly positive comments on the VR experience, many commented that they loved it or thought it was cool, amazing, or awesome.

TABLE VIII
OPEN-ENDED QUESTION RESULTS FOR BOTH STUDIES

Application	Erosion	Renewable resources
Most common Positive feedback	Immersiveness, Fun, Liked submersible, Interesting	Immersiveness, Informative, Interaction, Fun
Most common Negative feedback	Dizzy, Poor graphics	Difficulty, Volume
What did you learn?	Erosion, Oral history	Crabbing business, Renewable resources
Most common other comments	Cool, Loved it	Amazing, Awesome, Loved it

IV. DISCUSSION

As stated in the results, the positive normalized gain shows the average student improves slightly in testing after completing the VR application. Due to time constraints, a low number of testing questions were asked, and this could have contributed to the lower gain. VR is a relatively new venue for educational applications; however, as graphics and interactive content increase in future VR applications, this gain should substantially increase. New low-cost VR mobile devices, such as the Oculus Go, will allow entire classrooms to be in VR for the cost of a few computer VR setups. This will allow more time for testing as rotating equipment would not be required.

Highly positive answers (agree or strongly agree) were shown for the erosion study at 93% and in the renewable resources study at 87%. Over 80% in each study commented that they liked the VR experience in the open-ended questions. This would suggest that this type of application was an enjoyable experience for users who welcome the opportunity to be applied for educational purposes.

The non-video gamer group tested in the renewable resource study showed on average 10% higher positive results for VR than the remaining participants. This is promising as it does not confine VR education to participants with experience using remote controls in video games.

In the erosion study, the most popular comments included enjoying the VR experience, or immersiveness, and the application being fun and interesting. Many also commented enjoying the CAD-modeled submersible environment. The most common negative feedback, shown in Table V, was dizzy and poor graphics in the erosion study. This study used the first three 360-degree camera rigs we used, Ricoh Theta S, 360 Fly, and the Panotek rig. Both the Ricoh Theta S and the 360 Fly used spherical cameras that had very poor quality in low light conditions. The Panotek rig used ten YI4K cameras, which shot in lower resolution due to firmware limitations in controlling all cameras at once.

For the renewable resources study, the GoPro Hero, iZugar, and YI 360 cameras were used, showing far superior resolution and higher clarity in low light conditions. Utilizing the higher resolution cameras resulted in much lower number of participants commenting on graphics quality. The poor graphic

comments on this study could be attributed to the 3D-modeled objects not having photorealistic textures.

As stated in the method section, the Panotek, GoPro Hero, and iZugar camera rigs all require post processing in the form of stitching and editing to align all of the videos. Processing many cameras takes more time and there are more stitching issues than with the dual spherical cameras.

V. CONCLUSION

As shown in the results of each study, after playing the ten- to 20-minute immersive application, students showed improvement on the post-test, and well over 80% of the comments about the VR experience in both studies were positive. When finished, many students expressed that they enjoyed the experience and would like to play more. This type of application has been shown to be promising as an educational tool that students appreciate.

VI. RECOMMENDATIONS FOR FUTURE EDUCATIONAL VR APPLICATIONS USING 360-DEGREE VIDEOS:

- Use high-resolution two-camera spherical rigs that have real-time stitching.
- Use a mix of 360-degree photos and videos with 3D-modeled content with interaction through learning activities to reinforce learning.
- Embed feedback mechanisms, such as voice-over, in the design of the learning environment.
- Have photorealistic textures on 3D models to blend with actual 360-degree photos and videos.
- Use teleportation instead of controller-based walking to mitigate perceived motion sickness effects.
- Long-term retention should be assessed by testing participants a week or more following the application as long-term retention has shown to be an advantage for VR [30].
- Assessment techniques should be used that compare the relative effectiveness in learning outcomes using VR techniques against traditional teaching methods.

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