

Virtual Reality and Its Application in Environmental Education

by

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Executive Summary

Virtual reality, or VR, is a technology that can simulate a realistic environment. After decades of development, virtual reality is largely applied in various fields, including engineering, medicine, and education. People can experience virtual reality using VR headsets, desktop software, and mobile devices. The characteristics of VR being both immersive and interactive make it a suitable tool for education. In addition, 360-degree materials are one of the contents that can be experienced by VR and provide high-level immersion because 360-degree videos/images can occupy the vision of the audience from all angles.

The objectives of this project are to investigate the effectiveness of using VR in environmental education by reviewing previous studies, and produce a 360-degree VR learning product that can be used for educating entry-level learners of marine science.

From the results of the literature review, previous studies of applying VR in geography, environmental chemistry and other types of environmental education all indicate that it is effective to use VR as a tool for environmental education. Additionally, referring to the principles of materials for environmental education proposed by the North American Association for Environmental Education (NAAEE) in 2021, the feature(s) of VR can address the requirements of each principle, therefore serving as an appropriate tool.

The next step for this project is to create a 360-degree VR learning application for environmental education. The materials used in this project were collected in the western Antarctica Peninsula region during February to March 2019, using a Freefly Alta hexacopter (a six-rotor drone). The camera that took the 360° videos and images is a GoPro Fusion 360 Camera. The camera consists of two separate cameras, each filming a 180° view. After acquiring the video materials, the author used a computer software named GoPro Fusion Studio to stitch two 180° videos to create a 360° video. After producing the 360° materials, the author used the 3D Vista software package to add interactive features to the 360° materials, features include texts, information windows, pop-up images/videos, and directions to external websites.

Using the materials above, the author created a nine-scene 360° VR learning product that follows a storyboard designed by the author. The storyboard is aimed to imitate a 15-minute class, including an introduction, main contents, discussion, and summary. The final product contains the following scenes and interactive features, each scene being a panorama or a 360° video:

- (1) Introduction to Antarctica, with information windows about glaciers and the research vessels, and direction to an external web page.

- (2) Introduction to Palmer Station and research team, with information about the station and people, and web page of life on the research vessel.
- (3) Technology – drones, with information about the main parts of the drone and the camera we use.
- (4) Technology – tags, and introduction to Antarctic minke whale, with videos of Antarctic minke whales and tags, information about whales and tags.
- (5) Ice and minke whale habitat, with information about why ice is important for Antarctic minke whale habitat.
- (6) Research – minke whale tagging, with video and information about the research activity.
- (7) Other animals, with information of animals such as seals and humpback whales.
- (8) Reflection on climate change, with directions to web pages about the climate change situation in Antarctica, and information about how climate change impacts Antarctic minke whales.
- (9) Summary, with conclusion text boxes.

In addition to the linear navigation of the storyboard, there is a menu function that allows the audience to navigate themselves and not need to follow the storyboard, giving them more freedom and control over the virtual experience.

The final VR product is available at <https://storage.net-fs.com/hosting/7439318/0/>.

This product can serve as a tool for environmental education with the immersive experiences and interactive features it provides, which could help the audience focus on the key messages. In addition, if the storyboard could be designed ahead of data collection, the product could be more diverse and multifaceted.

In conclusion, this product can help entry-level learners to gain information on Antarctic minke whales and climate change. It is also the first to combine Antarctica, Antarctic minke whales, and climate change within a VR application, serving as an example of how VR can be applied in environmental education.

Virtual Reality and Its Application in Environmental Education

Abstract

This paper introduces the basis of virtual reality (VR), describes the benefits of applying virtual reality technology in environmental education, and presents a 360° VR product that focused on whales in Antarctica. According to the results of previous studies in this field, virtual reality can assist environmental education in many ways, including providing an affordable substitute for field trips. However, currently, there are a few challenges that need to be resolved. The product of this study was produced by multiple computer software systems, containing nine scenes of 360° videos or panoramas with interactive features. This VR product can serve as a tool for entry-level learners of marine science to acquire information about Antarctica, Antarctic minke whales, and climate change, in a compelling and fun way. In conclusion, it is practical and beneficial to apply virtual reality as a tool in environmental education.

1. Introduction

1.1 Virtual Reality

Virtual reality (VR) is a technology that can simulate a realistic environment. The idea of virtual reality was first put forward and developed by Morton Heilig in the 1950s. He developed an immersive, multi-sensory machine called Sensorama, which was known as one of the earliest VR systems (Rheingold, 1991). Yet, the Sensorama differed significantly from the modern VR headset. Later in the 1960s, Ivan Sutherland and his research team developed the first operational interactive head-mounted display system (Schroeder, 1993).

After decades of research and development in VR technology, there are now different forms of equipment to experience VR. Using different devices can change the immersion level of the VR experience. A highly immersive VR experience usually requires a head-mounted display (HMD) (Figure 1).

An HMD is a helmet-shaped device that provides a three-dimensional view and tracks the movement of the user to update the HMD view accordingly. Non-immersive VR systems, also known as a desktop VR systems, are another option for VR experiences (Chen, 2010).

Currently, it is generally acknowledged that the core benefits of VR are immersion and interactivity (Zheng, Chan, & Gibson, 1998). Concerning these two principles, there are five important features of VR technology that enable it to simulate a realistic environment and provide users with high-level immersion and interactivity (Wickens, 1992):



Figure 1 Head-mounted Display (HMD)

1. *Three-dimensional viewing*: providing a more realistic environment than two-dimensional viewing.
2. *Dynamic display*: making user's experience more realistic.
3. *Closed-loop interaction*: when using a VR system, the user is an active navigator as well as an observer, meaning the user has more control over the virtual world.
4. *Inside-out frame of reference*: also known as ego-referenced frame, creating a virtual world perspective akin to that of a camera placed on the explorer's head.
5. *Enhanced sensory experience*: the headset and gloves will record the user's movement and provide feedback to the VR system, therefore producing a better experience.

All the characteristics stated above make VR a suitable tool for environmental education. In chapter 2, there will be a more detailed illustration of how VR can benefit environmental education.

1.2 360-degree VR Materials

360-degree images and videos are one of the new multimedia types that provide an immersive experience and can be experienced using VR. 360-degree videos are also known as surround or immersive videos. These videos are produced by filming every direction simultaneously, usually using an omnidirectional camera or a collection of cameras. Different from a traditional display, 360° videos provide a seamless view that occupies the vision of the viewer, providing more immersion for the audience (Xu, Li, Zhang, & Le Callet, 2020). Most 360° videos can be viewed on a normal flat display where the audience has greater control over the direction while watching. Another way to view a 360° video is on a display arranged in a sphere, giving the audience a spherical and immersive view.

1.3 Objectives

The objectives of this study are to (1) explore the effectiveness of using VR technology in environmental education from previous studies through a literature review, (2) reflect on the pros and cons of current VR-based education methods, and (3) create a 360° VR product that is easily accessible for most people and aimed to educate entry-level marine science learners about climate change in Antarctica and its impact on Antarctic minke whales.

2. Virtual Reality in Environmental Education

2.1 The Benefits of Applying VR in Environmental Education

Since virtual reality was first developed in the twentieth century, it has been applied in many fields, including engineering, medicine, space exploration and communication (Zheng et al., 1998). Education is among the domains that are influenced by VR technology. The first experiment of applying VR in education was conducted in 1992, evaluating the potential of VR as a learning tool. The feedback from learners was

generally positive (Bricken & Byrne, 1993). Also in the 1990s, Taylor and Disinger (1997) explored the possibility of VR being applied in the field of environmental education through surveys of environmental education practitioners and VR developers. The survey results showed that VR is viewed as a potentially beneficial tool in environmental education according to the interviewees (Taylor & Disinger, 1997).

In addition, a study indicated that VR can provide three main advantages to education (Martín-Gutiérrez, Mora, Añorbe-Díaz, & González-Marrero, 2017):

- *Increasing students' motivation and engagement.* According to Salzman et al. (1999), VR systems could provide highly engaging experiences and contribute to a greater focus of learners on the learning topic. Due to the realistic virtual environment it provides, VR allows learners to experience the environment that is relatively difficult to reach in the real world, strengthening the connection between learners and the environment, therefore benefiting environmental education (Taylor & Disinger, 1997). Later, in the twenty-first century, there were more studies indicating that VR technology could improve students' academic performance and motivation by increasing students' engagement (Gutiérrez, Domínguez, & González, 2015; Harris & Reid, 2005).
- *Providing more interaction than conventional learning materials.* VR technology can promote skills of learners such as decision-making when interacting with virtual environments (Martín-Gutiérrez et al., 2017). VR can also provide instant feedback for learners to improve. In addition, VR products with interactive features can improve the understanding and immersion level of learners by making them more actively involved (Choi, Yoon, Song, & Choi, 2018).
- *Providing virtual field trips that are more affordable and accessible than real field trips.* Please refer to section 2.4 for more detailed information.

2.2 Previous Experiments of Applying VR in Environmental Education

In 2014, Merchant et al. did a meta-analysis of a total of 69 studies that used virtual reality in education to investigate the effectiveness of desktop-based VR technology in education (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). In terms of test results, this study revealed that VR-based instruction produces positive results. The knowledge retention level of the game-based VR instruction method can exceed that of conventional short-term learning.

Tudor et al. investigated students' experience of using a mobile VR application for a virtual geography field trip in 2018 (Tudor, Minocha, Collins, & Tilling, 2018). The authors used Google Expeditions, a smartphone-based virtual reality application. The study result showed that after using this application in class, students became aware of the impacts of large-scale development, and gained knowledge about the implication for the environment and proposed suggestions.

In 2019, Fung et al. conducted a study using a VR platform in environmental chemistry education (Fung et al., 2019). The authors used a web-based online VR platform named edu2VR to simulate an overseas field trip for undergraduate students.

After two trials of this VR technique, the majority of the students reported a positive experience. However, the main challenges of this study were the limitation of the application and disorientation after a long time of using the VR head-mounted device.

2.3 Key features of VR and Environmental Education

In order to understand how VR can benefit environmental education, we should consider how it meshes with the core principles of environmental education. Specifically, we should consider how VR can augment these principles to achieve high-level and -quality environmental education. In this paper, the author is referring to the following key principles proposed by North American Association for Environmental Education as standards ((NAAEE), 2021):

1. *Accurate and inclusive*: the materials for environmental education should be accurate and able to reflect the diversity of the environment in all aspects.
2. *Emphasis on skills building*: environmental education should aim at building lifelong skills for learners.
3. *Depth of understanding*: instructional materials should foster learners' personal awareness and environmental literacy.
4. *Personal and civic responsibility*: personal and civic responsibility serve as an important basis for environmental decision-making and action.
5. *Instructional effectiveness*: it is important for education materials to create effective and inclusive learning environments for all learners.
6. *Usability*: the materials should be well-designed and easy to use for both educators and learners.

According to these principles and above stated the characteristics of VR stated in the Introduction, we can build connections between environmental education and VR tools and techniques, and summarize how VR can serve as a suitable tool and provide appropriate materials for environmental education. The summary is shown in Table 1, presenting the principles for materials of environmental education, how each principle can benefit from some feature(s) of VR, and how the product of this study can address these requirements.

In addition, among the learning materials of VR, 360° videos and images can create a fully immersive environment and serve as a suitable tool for environmental education. According to Choi et al., 360° panoramic VR content can create a more immersive experience than regular photographs or videos, because 360° contents can simulate the real environment and make the user feel like being in the place (Choi, Yoon, Song, & Choi, 2018).

Table 1 Key Features of VR and Environmental Education

Principles for materials of environmental education (NAAEE, 2021)	Key feature(s) of virtual reality that benefit environmental education (Wickens, 1992)	How the feature(s) of VR assist the principle for environmental education	Feature(s) of 360° VR learning materials in this study in Antarctica in 2019, which can be used via VR headset and desktop.
Accurate and Inclusive	Three-dimensional viewing Dynamic display	Both 3D and dynamic display help to create a realistic environment in any area, of any time, and of any form.	The 360° videos and panorama of this study were taken in Antarctica in 2019, which can be used via VR headset and desktop.
Emphasis on Skills Building	Closed loop interaction	Skills are developed when users learn and practice through interaction with the virtual world.	The interaction features of 360° learning materials allow learners to interact with features of Antarctica.
Depth of Understanding	Closed-loop interaction Inside-out frame of reference	The experience of interaction and ego-referenced frame provided by VR can assist the learners to better understand the environment.	The learning materials of this study was taken by an aerial drone, simulating the perspective of flying with the drone.
Personal and Civic Responsibility	Inside-out frame of reference	The ego-referenced frame provides a hypothetical situation where the learner is situated in the environment, building a connection between learners and the environment, therefore cultivating their responsibility for the environment.	The learning materials focus on Antarctic minke whale, which is a species listed as Near Threatened under the Red List of International Union for Conservation of Nature (IUCN) (Risch, Norris, Curnock, & Friedlaender, 2019). By interacting with the learning materials, learners will form a closer relationship with the creatures.
Instructional Effectiveness	Inside-out frame of reference Enhanced sensory feedback	VR is usually aimed for a single user, which makes it effective for learners. In addition, the enhanced sensory feedback also increases effectiveness as learners can receive prompt change in the virtual world.	The learners have control over the interactive features, which enables them to learn at their own pace. The learning materials can also be tailored for learner's need.
Usability		VR can simulate a realistic world and provide an opportunity for learners to experience the virtual environment without going to a certain place, therefore showing usability.	The 360° learning materials of this study can be applied on VR headset, desktop, and mobile device, which is achievable for most people. The materials simulate the environment in Antarctica, enabling people to learn about a place that is physically difficult to reach.

2.4 Virtual Field Trip

Field trips are often considered essential to environmental education because they connect textbook knowledge with realistic environmental conditions and authentic experiences. The in-situ experience of field trips can increase learners' depth of understanding and build their responsibility for the environment.

However, field trips sometimes can be difficult to provide for the following reasons: (1) field trips can be expensive for institutes or students to afford; (2) some research sites are not easily accessible (e.g. Antarctica, Mount Everest); (3) people with certain disabilities might not be able to travel easily.

To address the issues above, one practical alternative for field trips is participation in virtual field trips. Virtual field trips using VR equipment may exhibit the following advantages (Tudor et al., 2018):

1. Similar to a real field trip, a virtual field trip provides a virtual environment for students to connect textbook knowledge with imagery of the real environment.
2. Virtual field trip provides more affordable alternatives to real field trip. The price of VR equipment is lower than conducting a real field trip. In addition to equipment such as HMD, there are even less expensive alternatives that don't require headsets: 3D virtual environments on desktops and mobile devices.
3. A virtual field trip requires less time than a real field trip, saving the time of travelling and preparing.

3. Challenges

Despite the advantages of applying VR in environmental education, the VR equipment currently being used in class may exhibit the following issues (Fung et al., 2019): (1) Extended wearing of a VR headset/head-mounted display may cause disorientation or dizziness; (2) Some activities that will be conducted on real field trips cannot be completed through VR, such as sample collection and water/air quality survey; (3) Learner's ability to explore and control over the virtual world is limited within the prepared scenario.

Among the challenges, the disorientation could be relieved by decreasing the time of the virtual field trip. As for the limitation of conducting in-situ experiments, the purpose of using VR in environmental education is not to replace the real field trip, but to provide a practical substitute for a field trip.

4. Product: A 360° VR Product for Environmental Education

In the present study, the author produced a 360° VR application product for learners to explore Antarctica, simulating the situation of flying with a drone above the ocean, and learning about Antarctic minke whales and other aspects of the Antarctic Peninsula ecosystem. This product can serve as a virtual field trip tool, providing opportunities for learners to experience a place that is relatively difficult to reach. The product can be viewed via VR headsets, desktops, and mobile devices, providing convenience to the

audience.

4.1 Research Materials

The 360° videos and images used in this study were collected in the western Antarctica Peninsula region, including areas around the Palmer Station (Figure 2) using drones, from February to March of 2019.

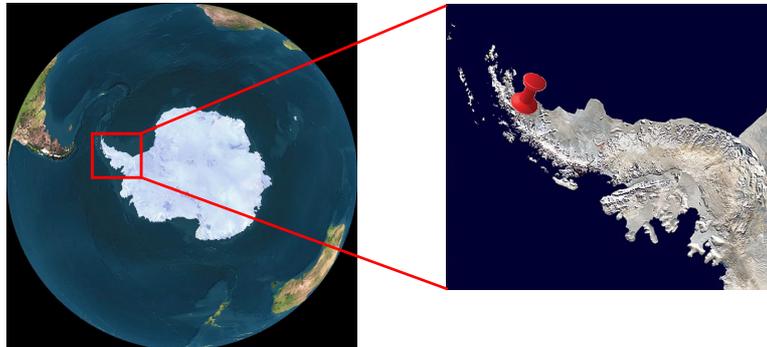


Figure 2 Study Area

The drone used for carrying cameras and collecting video materials during research was a Freefly Alta 6 hexacopter (a six-rotor drone). The 360° videos and images were taken using a GoPro Fusion 360 Camera, which consists of two separate cameras on the front and back, each filming a 180° view (Figure 3, b, c).



Figure 3 GoPro Fusion 360 Camera. (a) Pack. (b) Front. (c) Back.

4.2 Methods

This study uses 360° materials to produce interactive learning materials for learners to explore Antarctica. The 360° videos are produced by stitching the paired 180° video scenes taken with a GoPro Fusion 360 Camera, using a computer software named GoPro Fusion Studio. The GoPro Fusion Studio is designed to stitch videos taken by GoPro Fusion 360 Camera and make 360° videos and panoramas. Adobe Premiere was also used to select and screenshot some of the high-light scenes from the videos to produce panoramas that match the topic.

After rendering the 360° videos and images, we use a 3D Vista software package to add interactive features to the 360° learning materials. 3D Vista enables users to add

interactive features to photos, videos, panorama, and 360° videos. Features include but are not limited to text boxes, information windows, pop-up images/videos, and directions to external websites and other internet resources. It can also provide menu and navigation functions, enabling linear or scripted navigation of the learning materials as well as exploratory experiences.

4.3 Storyboard

Using these 360° videos and images, the author created a storyboard that introduces Antarctica, Antarctic minke whales, the research the Marine Robotics & Remote Sensing (MaRRS) lab carries out in Antarctica, and includes a brief reflection on climate change (Figure 4). The storyboard is designed to last about 15 minutes, aimed at entry-level learners of marine and environmental science. There are buttons that the audience can click to go back and forth from each scene, following the storyboard. In addition, there is a menu that allows the audience to navigate themselves freely and not necessarily need to follow the storyboard, giving them more freedom and control over the virtual experience.

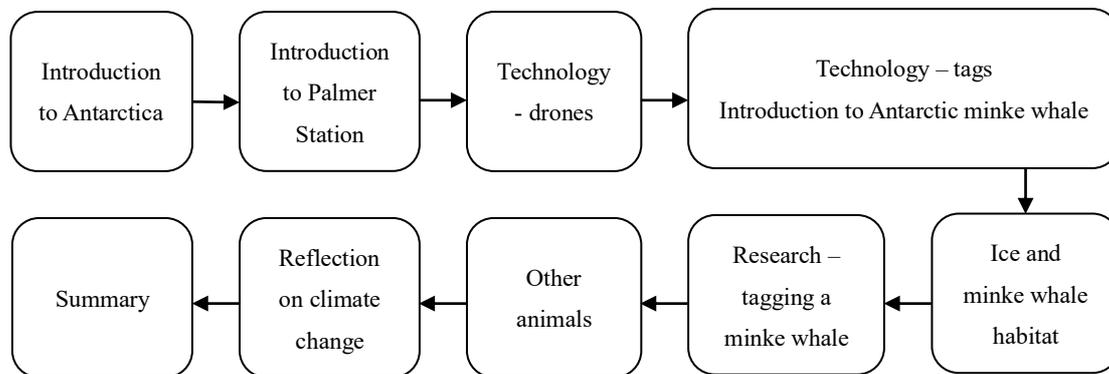


Figure 4 Storyboard of the 360° product

This storyboard serves as an outline for the product, forming a 15-minute class structure, from introduction to main contents and summary.

The first two panoramic scenes of the introduction give the audience an overview of Antarctica, with click-on information windows and directions to external web pages that provide information to the audience about Antarctica and Palmer Station in general.

Following the introduction, there will be two 360° video scenes introducing the technology we used for research, namely, drones and tags. For the drone scene, there will be click-on information windows on drones during the taking off video. The tags we used on the minke whale are named Customized Animal Tracking Solutions (CATS) tags. This type of tag tracks the movement of a whale underwater, either moving vertically or horizontally. There will be click-on videos of the Antarctic minke whale in a closer view and information on the tags.

Following that, there is a scene explaining the relationship between ice and the Antarctic minke whale habitat: Antarctic minke whales rely on ice to avoid their main predators, killer whales, and to forage.

Building on the tag introduction scene, the next scene is a 360° video presenting the process of successfully tagging a minke whale. The audience will learn how to tag a

minke whale with the researchers.

After introducing other animals in Antarctica, the storyboard will focus on a reflection on climate change. With a panorama of glaciers and ice in Antarctica, the audience will gain information about the change in glaciers in the past few decades and how this change impacts Antarctic minke whales. The interactive features include directions to web pages about climate change in Antarctica and the influences on minke whales.

Finally, there is a summary page that reflects on climate change and appeals to people to take measures to mitigate climate change and protect Antarctic minke whales.

4.4 Final Product

The final VR product is available at: <https://storage.net-fs.com/hosting/7439318/0/>.

4.5 Next Step

The final product of this study can be applied in the community education program in Beaufort, North Carolina, United States. After the first trial of the product, feedback will be collected on what the learners gain from this VR experience, and what the learners think the product should improve.

It is important to note that the first version of the product is aimed at entry-level learners of marine science. In future, the 360° videos, images and interactive features can all be edited and customized to fit the need of learners of different levels.

5. Discussion

5.1 Data Collection

The storyboard was designed after the data collection period, meaning that the 360° materials used for this study were collected without the purpose of making a storyboard and a VR experience. If the storyboard was designed before collecting data, we could collect materials with specific aims and thus might have more diverse and multi-faceted materials for the product, such as underwater 360° videos.

5.2 Effectiveness of the Product on Environmental Education

Reflecting on the contents of Table 1, this product provides accurate and inclusive 360° materials for environmental education. The 360° product can provide a highly immersive and interactive experience to the audience, enabling the audience to focus on the topics more than many conventional education methods. By taking a self-centered perspective, this product can assist the audience's depth of understanding of the virtual environment by being a part of the environment, thus also cultivating the personal and civic responsibility of the learners. In addition, the interactive features of the VR product can assist the audience to focus on the highlight of each scene, differentiating it from a video for entertainment and therefore increasing the instructive effectiveness of the product. As for usability, the product is easily accessed using VR headset, desktop, and mobile devices, being convenient for most users.

6. Conclusion

Previous studies of applying VR to the education field indicate that VR is a suitable tool for modern environmental education and can provide materials that address the principles of environmental education.

The 360° VR product from this study provides learners with opportunities to explore Antarctica with easily available devices such as desktops, mobile devices, and VR headsets. The storyboard of the product can assist the audience to follow the structure of a short class and gain information. This product is also the first to combine Antarctica, Antarctic minke whales, and climate change through a VR technique, serving as a case study of using VR in environmental education.

Rapid development in technology can further lower the price of VR products and equipment. In the future, we will anticipate an increasing trend in using VR in environmental education, benefiting more learners around the world.

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