electronics

Article

Designing Immersive Virtual Reality Simulation for Environmental Science Education

Yongjoo Cho [1] and Kyoung Shin Park [2,*]

[1] Department of Computer Science, Sangmyung University, Seoul 03016, Republic of Korea
[2] Department of Computer Engineering, Dankook University, 152 Jukjeon-ro, Suji-gu, Yongin-si 16890, Republic of Korea
* Correspondence: kpark@dankook.ac.kr; Tel.: +82-31-8005-3161

Abstract: Recently, severe environmental changes, such as global warming, climate change and environmental pollution, have become expected, and thus environmental education is becoming essential. The purpose of environmental education is to instill awareness in students to recognize and solve environmental problems. Virtual reality provides students with a spatial and temporal experience similar to reality, and it can increase their understanding of knowledge through immersion and interaction compared to traditional learning. In previous studies, virtual reality for education has mainly focused on experience, but it is difficult to find examples for environmental education. Hence, this research proposed an immersive virtual reality simulation for environmental education based on the virtual ecosystem model. It also presented two applications developed based on this simulation. This research aims at encouraging students' active participation and motivation to solve the environmental problems while experiencing the results of interaction related to environmental factors in a virtual environment.

Keywords: environmental simulation; environmental monitoring; virtual ecosystem model; virtual reality; immersion; interaction; environmental education

Citation: Cho, Y.; Park, K.S. Designing Immersive Virtual Reality Simulation for Environmental Science Education. *Electronics* **2023**, *12*, 315. https://doi.org/10.3390/electronics12020315

Academic Editors: Yiyu Cai, Xiaoqun Wu, Qi Cao and Xiao Zhang

Received: 29 November 2022
Revised: 4 January 2023
Accepted: 5 January 2023
Published: 7 January 2023

1. Introduction

Natural disasters, such as forest fires, floods, heat waves, and earthquakes that have recently occurred around the world are the result of climate change. The continued use of fossil fuels and the reckless development of the natural environment, along with the expansion of industrialization and urbanization, have resulted in environmental destruction and global warming, and various environmental pollution problems have reached a serious situation threatening the survival of mankind. Experts warn that if the current trend continues, extreme climate change, such as glacier loss, desertification, and sea level rise, will inevitably accelerate further. Therefore, immediate human action in a global context, such as reducing greenhouse gas emission, is needed to return to a safe climate. However, it is difficult for people to have ecological awareness, since environmental problems manifest over decades and hundreds of years, and thus the importance of environmental education may be overlooked [1].

Environmental education has not been considered a standalone subject in the traditional K-12 curriculum but rather an additional or elective subject in science or social studies [2]. In addition, it is difficult to expect educational outcomes for environmental education through case-oriented knowledge education conducted in the classroom. However, environmental education aims not only to convey knowledge to students but also to realize the seriousness of environmental problems in real life and teach them to practice for the environment. In that respect, field trips are often considered essential to environmental education because they connect textbook knowledge with real life. Through scientific investigation and inquiry of in-site field trips, students are able to identify and experience environmental issues and enhance their understanding. However, field trips can be expensive to afford, and some places, such as the Arctic and Antarctica, are not easily accessible.

Recently, low-cost immersive virtual reality, augmented reality and mixed reality technologies, such as Oculus Rift, HTC VIVE, and Microsoft HoloLens, have been popularized to the public. They have been used in various application domains, such as education, engineering, military training simulations, and medical treatments. In the case of immersive virtual reality and augmented reality applications, education accounts for the largest proportion among all applications fields, and science education is the most researched and utilized within the education field, followed by architecture, engineering, and medicine [3–5]. Virtual reality can provide an environment in which variables that are difficult to control in reality can be easily controlled. By providing appropriate interactions, not only can it arouse interest in students but it can also replicate through a virtual environment experiments that are difficult or impossible to experience in reality.

Past research on virtual reality or augmented reality applications in education mainly focuses on the effects centered on user experience. It is apparent that the use of virtual reality in environmental education has not yet been explored extensively compared to other subjects [1,3–8]. Research on virtual reality or augmented reality for environmental science is largely divided into application development or user studies aimed at environmental monitoring [9–13], ecological awareness [14–21], and environmental education [22–31]. Usability research showed that virtual reality or augmented reality experience can increase participant interest, concern, or knowledge about environmental issues [32–44]. Most focused on the visualization or monitoring of environmental data causality, some considered the temporal aspects of the data, and others supported data measurement.

Based on the characteristics of previous studies, this research proposed a virtual ecosystem model composed of causality, spatial-temporal data, data population and instrument, and persistent world concepts. The environment changes over a long period of time and by various factors. By utilizing virtual reality technology, it is possible to realize an environment that transcends time and space, and the environmental problems that would take decades or hundreds of years to come to fruition in the real world can be directly experienced within five minutes. In this paper, we presented the design and implementation of a virtual ecosystem model necessary for the development of immersive virtual reality simulation for environmental education. Then, we presented two applications developed based on this simulation. The goal of this research is to help ease the construction of various immersive virtual reality applications for environmental education for students to recognize environmental issues and become pro-environmental behavior.

This paper is structured as follows. Section 2 reviews the previous work on the use of virtual reality and augmented reality in environmental education. Section 3 presents the design principles for a virtual ecosystem model. Section 4 describes the system architecture of immersive virtual reality simulation for environmental education based on the virtual ecosystem model. Section 5 describes the two applications based on this simulation, and Section 6 describes a preliminary user study on evaluating the usability and the virtual ecosystem model of application. Finally, Section 7 presents a conclusion and discusses the directions we need to take for future research.

2. Related Work

In the field of environmental science, research related to virtual reality and augmented reality is mainly focused on application developments or user studies. It is largely divided into environmental monitoring, ecological awareness, and environmental education. Virtual reality and augmented realty research for environmental science was not extensive in the early 2000s, but it increased around the 2020s when natural disasters caused by climate change surged.

Environmental monitoring refers to the processes and activities designed to measure, identify, and analyze environmental parameters to understand a phenomenon [9]. Veas et al. introduced a tablet PC augmented reality platform that visualizes a 3D terrain overlaid with on-site environmental data for environmental monitoring [9]. Studer et al. presented an augmented reality application that shows a daphnia toxicity meter implemented with actual water quality data of the Hamburg River [10]. West et al. presented MetaTree, a mobile augmented reality application for imaging and monitoring the status of an urban forest to create cultural engagement with urban ecology [11] and then added the visualization of the urban forest in changes across various spatial and temporal scales [12]. Frajberg et al. presented PeakAR, a mobile augmented reality application, which encourages users to gather environment data for mountain exploration, such as the analysis of snow coverage for water availability prediction and the monitoring of plant diseases [13].

Ecological awareness reflects people's concern about the impact of their behavior on the environment. Santos et al. presented eVision, a mobile augmented reality application, which allows users to inspect their surroundings with mobile devices to search for pollution sources and virtually clean the pollution [14]. Nim et al. presented an immersive interactive tour on the Great Barrier Reef (GBR) in Australia, combining tiled displays and head-mounted displays to dynamically visualize coral damage information based on users' footprint inputs [15]. McGinity presented various properties of virtual reality or augmented reality to increase environmental awareness and change to green consumer behavior [16]. Ke et al. presented an immersive multi-sensory virtual reality application called Embodied Weather, which is designed to promote public understanding of extreme weather [17]. Huang et al. presented a virtual reality application visualizing scientific data of an ecological model, where users can explore the impacts of climate change on different tree species [18,19]. Torres et al. developed an iOS-based augmented reality application called Aire that visualizes the complex scientific concept of air pollution in the air in order to increase public awareness [20]. Ramachandran et al. presented USC Air, a mobile augmented reality application for air quality monitoring to encourage people to contribute to the environmental interventions [21].

Environmental education aims to help people to acquire knowledge of the environmental issues, which leads to pro-environmental behavior. Winn et al. developed Virtual Puget Sound (VPS), which was an immersive virtual reality learning environment created by bathymetry, topography, and data generated by the Princeton Ocean Model (POM) of Puget Sound. The purpose was to teach oceanography principles to students [22]. The EcoLearn group at Harvard Graduate School of Education supports learning about complex causal dynamics of ecosystems using immersive VR and AR technology [23]. EcoMUVE is an immersive virtual reality simulation that can improve students' learning environments and enhance their understanding of the learning topic. EcoMUVE has pond and forest modules; each module follows a 45 min model for 10 lectures, allowing students to immerse themselves and learn about the ecosystem of ponds and forests [23]. EcoXPT is an inquiry-based curriculum on ecosystem education that encourages students to experience immersive experimentation [23]. EcoMobile is an extension of EcoMUVE, where students go on field trips to real pond environments and use augmented reality devices to explore whether ecosystem education is more effective by combining real ecosystems infused with virtual resources [24].

Srisuphab et al. developed ZooEduGuide, an Android-based mobile augmented reality game for Zoo designed to motivate students to learn about animal and wildlife along with ecological footprints [25]. Theodorou et al. developed an android mobile augmented reality application to teach climate change and renewable energy concepts to students [26]. Clayborn et al. developed Butterfly World 1.0, a virtual reality 360 video application designed to teach students about butterflies and plants in dry forest ecosystems in Florida Keys [27]. Mawsally et al. developed an android mobile virtual reality educational game called EarthHero to help students learn about saving the environment from the dangers of pollutions [28]. Taulien et al. developed a Microsoft HoloLens mixed reality application, which allows users to explore the virtual underwater of the Baltic Sea and the user tests showed that such an environmental simulation provided an authentic insight into the Baltic Sea habitat [29]. Liu et al. developed an immersive virtual reality application called

Melting Sea Ice, which provides students with direct experience of the causes of sea ice loss in Antarctica and the Arctic from the 1950s to the 2020s due to global warming [30]. Sermet et al. developed the GeospatialVR framework for collaborative environmental simulation that can run on web, desktop and mobile devices, as well as VR headsets [31].

There are many studies on the use of virtual reality and augmented reality for environmental education. Winn et al. compared the interactive virtual reality with a real field trip at sea to learn oceanography and found that VR helped students connect with what they learned from it to other content they learned in class [32]. Baily et al. conducted a study to investigate the impact of vivid and personalized messages in virtual reality on energy-saving behavior related to hot water use, and vivid messages was the most effective in promoting pro-environmental behaviors [33]. Fonseca et al. compared Oculus Rift and hand-held displays for 360 video on meat consumption and its environmental impact and found that the presence and emotional impact provided by VR affected users' eco-friendly attitudes [34]. Tudor et al. assessed a comparison between a mobile virtual reality application using Google Expeditions and the physical field trip to learn about south-east England and revealed that students became aware of the environmental issues, acquired environmental knowledge, and suggested actions for protection of the environment [35].

Hsu et al. assessed direct and/or ambient exaggerated feedbacks on a water conservation immersive virtual reality game and found that VR caused significant changes in cognition and behavior intention [36]. The ocean acidification simulation details the damage that carbon pollution is doing to the oceans and calls attention to what individuals can do to protect the oceans. There was a study conducted on virtual field trips using this simulation compared against the real field trips [37]. Participants learned the causes and effects of ocean acidification through the simulation from a diver's point of view or a coral reef's point of view. The result showed that the more people experienced this simulation, the more knowledge and interest in ocean acidification grew. Kenneth et al. conducted a user study on Virtual Reality Ecoliteracy Curriculum (VREC) lessons using 360 photos and videos and showed the improvement of learners' environmental knowledge and engagement [38].

Chang et al. evaluated the effectiveness of the virtual reality activities for students to learn knowledge about a geological park in earth science class and found that VR with the peer assessment learning approach had higher learning effectiveness [39]. Chirico et al. evaluated three kinds of display formats, numerical, concrete, and mixed, in immersive virtual reality environments about plastic consumption, recycling, and waste and found that concrete and mixed formats were effective in designing virtual-environment-promoting pro-environmental behaviors [40]. Fokides et al. conducted research into environmental education on issues related to the protection of the Mediterranean monk seal by printed material, web-based application, and virtual reality groups and obtained that virtual reality could increase user enjoyment and motivation to learn [41].

Nelson et al. evaluated an immersive virtual reality 360 film about coral reefs and the importance of protecting them comparing positive and negative messages and found that VR was an effective way to raise awareness of environmental threats and encourage behavioral action [42]. Petersen et al. compared the effectiveness of providing pre-training in background information before versus during immersive virtual field trips to Greenland to learn about the effects of global warming and found that pre-training helped to improve transfer test performance [43]. Ruan evaluated the effect of VR technology on the environmental education of college students using the EduVenture VR application and found that VR had a better learning efficiency in environmental education and created a stronger sense of environmental protection than traditional instruction [44].

Table 1 shows a summary of the key features of virtual reality or augmented reality application for environmental science. It describes the lessons of environmental education and interaction characteristics for the existing research. When the negative impact of human behaviors on the environment is visualized, users can focus on the loss, and through the positive impacts of human actions, they can be interested in protecting the natural environment and ecological awareness. Overall, virtual reality or augmented reality exploration and immersive experiences helped users learn various environmental education lessons. Many of these applications supported users in seeing data visualization or in monitoring the causal relationships affecting the environment. Some have considered the temporal aspect of environmental data, and others supported inquiry learning by allowing users to directly measure the environmental data. However, all of these applications mainly focused on one-time education on lesson plans and did not support for persistent, long-term use.

Table 1. Key features of virtual reality or augmented reality application for environmental science.

Application	Lesson	Interaction
Mobile AR platform [9]	Snow height, temperature over time	Sensor data monitoring
Fleabag AR [10]	Daphnia, water quality	Water quality monitoring
MetaTree mobile AR [11,12]	Urban forest ecology over time	Urban tree visualization
PeakLens mobile AR [13]	Snow coverage, plants over time	Geo-referenced image visualization of mountain range
eVision mobile AR [14]	Pollution	Clean pollution interactively
Great Barrier Reef MR [15]	Coral reef ecology	Coral damage visualization based on user's footprints
Immersive Media [16]	Plastic bags	Environmental awareness
Embodied Weather VR [17]	Weather, energy usage over time	Four types of weather scenario
Ecological model [18,19]	Climate, tree species over time	Two scenarios of VR
Aire AR [20]	Air pollution	Air pollution monitoring
USC Air mobile AR [21]	Air quality	Air quality monitoring
Virtual Puget Sound VR [22,32]	Tide, water, salinity over time	Inquiry learning
EcoMUVE, EcoXPT, EcoMobile EcoMod VR/AR [23,24,41]	Pond, forest ecology over time	Inquiry learning using instrument
ZooEduGuide mobile AR [25]	Zoo animals	Visualization
Climate change mobile AR [26]	Climate change, energy	Visualization
Butterfly World 1.0 mobile VR [27]	Butterfly, plant ecology	360 VR experience
EarthHero mobile VR [28]	Pollution and reduction	Mobile VR exploration
Baltic Sea MR [29]	Baltic Sea Habitat	Interactive VR exploration
Melting Sea Ice VR [30]	Polar ecology, global warming over time	Inquiry learning using instrument
Geospatial VR [31]	Environmental simulation	Web, desktop, VR/AR exploration
Virtual Shower VR [33]	Hot water usage	Interactive VR exploration
Meat consumption VR [34]	Meat consumption	360 VR experience
Google Expedition VR [35]	700 expeditions	Mobile VR exploration
Water conservation VR [36]	Water conservation	Interactive VR exploration
Ocean Acidification VR [37]	CO_2, ocean acidification	Interactive VR exploration
VR Ecoliteracy Curriculum [38]	Erosion, renewable resource	360 VR experience
Earth Science VR [39]	Rock erosion, deposition	360 photo
Plastic consumption VR [40]	Plastic waste recycling	Interactive VR exploration
Climate change VR [42]	Environmental threats	360 VR experience
Greenland VR [43]	Global warming	Interactive VR exploration
EduVenture VR [44]	Rain forest	Mobile VR exploration

3. Virtual Ecosystem Model

An ecosystem includes all living things within a specific area, including plants, animals, and organisms. These organisms interact with each other, as well as inorganic components, such as weather, land, sun, soil, climate, and atmosphere. This complex interaction of living things and the environments has been the basis for energy flow and carbon and nitrogen cycle. It is important to establish a virtual ecosystem that is well fitted to the lesson plan to utilize virtual reality as an environmental education tool. The concept of the virtual ecosystem model is to provide a dynamic virtual simulation that users can interactively influence with the environment [45]. This research used the virtual ecosystem model considering an ecosystem (time, space, organisms, objects, and environmental factors) for the construction of a virtual environment for environmental science education.

Time is modeled as a one-dimensional linear timeline but can be changed to a non-linear timeline according to the requirements in the virtual environment. Space is modeled as a three-dimensional space similar to the real world, and at the same time, the user should be able to feel the change of space affected by environmental factors. Organisms (such as human, animal, and plant) and objects (such as mountain, river, sea, and building) exist in time and space, and they are affected by the environmental factors. Environmental factors are natural phenomena (snow, rain, wind, and fog), temperature, humidity, day and night light change, and minerals (oxygen, ozone, carbon dioxide, nitrogen), and they can be measured by instruments. In addition, even if there is no user in the virtual environment, there must be changes according to environmental and human behavior factors.

In previous environmental education studies using virtual reality systems, it was confirmed that virtual reality supported immersion, engagement, and interaction, and VR experiences were helpful to students for transferring knowledge to real life [6]. In this study, by analyzing existing studies, the virtual ecosystem model is proposed to support a methodology that affects students' attitudes and behaviors toward environmental conservation. The virtual ecosystem model is composed of causality among ecosystem components, spatial-temporal data, data population and instrumentation, and persistent world simulation. This section looks at the virtual ecosystem model, analyzing characteristics inherent to the components.

3.1. Causality among Ecosystem Components

The first aspect of the virtual ecosystem model is that environmental factors are organically connected to each other and have causality. The natural environment consists of living things (such as plants, animals, and humans) and abiotic factors (such as light, temperature, carbon dioxide, water, air, and soil). These organisms and their abiotic factors should be interdependent in the virtual ecosystem. For example, a decrease in temperature and an increase in humidity when it rains. In addition, environmental pollution in soil, air, water quality, etc., destroys the natural environment, and these changed environmental factors will affect living things. Bad human activities can also disrupt many ecosystems or biomes.

3.2. Spatial-Temporal Data

The second aspect of the virtual ecosystem model is that it is interactively linked to the spatial and temporal fluctuations of environmental factors. In reality, the natural environment space continuously changes with the passage of time. Spatial-temporal data relate to both space and time. As for spatiotemporal data, there is periodic time-series data in which measurements are performed on a regular basis at a fixed location on a map, such as daily weather information, according to the characteristic that data can be located on the flow of space and time. In addition, there is an aperiodic time series method in which data are added according to the change of time using data whose data collection period is not constant, such as heavy rain, strong winds, wind storms, earthquakes, and wild fires.

In the field of ecology and environment science, the analysis of spatial and temporal variations in environmental factors and research on mutual influence are also being actively conducted. Some virtual reality applications for environmental education also considered the temporal aspects of environmental data [9,12,13,17,19,22,23,30]. In the development of virtual reality applications for environment education, as in the real world, it is necessary to create a virtual ecosystem modeled by spatial-temporal connection of various virtual environment objects and environment properties. In the virtual ecosystem model, spatial-temporal data should show continuity over time and changes in space. Through this, it is possible to provide a function for identifying characteristics changed by environmental factors for a long time centered on the space where the user is located. Such a virtual ecosystem can provide an expansive user experience for a space that reflects temporal changes.

3.3. Data Population and Instrumentation

The third aspect of the virtual ecosystem model is data population and measurement. To construct a virtual ecosystem for inquiry learning for environmental science education, it is necessary to redefine the user interaction with the attribute data of various types of environmental factors and objects according to a specific learning lesson plan. Ramasundram et al. stated that natural phenomena in the real world should be accurately defined as simulations and learners should be guided according to the scientific inquiry process in order to use virtual reality as an experimental environment for environmental education [46]. In previous studies, application developers had to directly input data or integrate them in accordance with the content scenario to set these environmental data, but there is a problem in that they need to be designed and developed differently depending on the lesson plan.

3.4. Persistent World Simulation

The fourth aspect of the virtual ecosystem model is persistent world simulation. Persistent world simulation is subdivided into "game persistence", "world persistence", and "data persistence". Data persistence ensures that all world data are not lost in the event of a computer system failure. World persistence means that the world continues to exist and can be used when players want to access it. Game persistence refers to the persistence of game events within the world. A user can leave and return to the virtual environment at any time, and the virtual environment must maintain a continuous environment state by establishing a causal relationship between environmental components. Whenever a user enters the virtual environment, the data they have played with in the previous game world should be shown, for example, the climate information, the number of crop seeds and plants, and the degree of contamination. The evolution of the environment should not disappear and should continue even after the user has exited.

4. System Architecture

Figure 1 shows the system architecture of immersive virtual reality simulation based on the virtual ecosystem model for environmental science education that consisted of simulation data, simulation server, virtual environment, and data instrument. Winn et al. described the simulations used in science education by dividing them into model-based simulation and physical simulation [32]. Model-based simulations simplify and abstract phenomena as much as possible so that students can grasp key concepts, while physical simulations reflect the appearance of real-world phenomena as they are. For example, scientific visualization is based on physical simulations that reproduce real phenomena. Meanwhile, this research used a simplified model-based simulation configured for environmental education so that the students could understand the phenomena as easily as possible. These features do not match the expected laws of physics but are new elements of the virtual world that are accepted by students [47].

4.1. Simulation Data

The virtual ecosystem simulation data include landscape (i.e., 3D map models), climate and weather (temperature and humidity), pollution (CO_2, N, P, O_2, O_3, and NaCl), vegetation (population of various plants), and animals (population of various animals). This simulation data are based on temporal coordinates and corresponding spatial coordinates of different eras so that the user can experience different spatial data according to time. To design and implement a virtual reality application for scientific inquiry learning in environmental education, it is necessary to define the environmental data settings according to the specific learning curriculum by matching the user interaction with the attribute data of various types of environments and objects. For example, when designing a virtual reality application for ocean acidification, carbon dioxide, the cause of ocean acidification, and the degree of ocean acidification should be set as variables. In this case, the degree of acidification in the virtual environment should vary depending on the conditions, and various conditions can be seen as user interactions in the virtual environment. In this research, JSON data format and scripts were utilized to help insert simulation data suitable for the lesson plan.

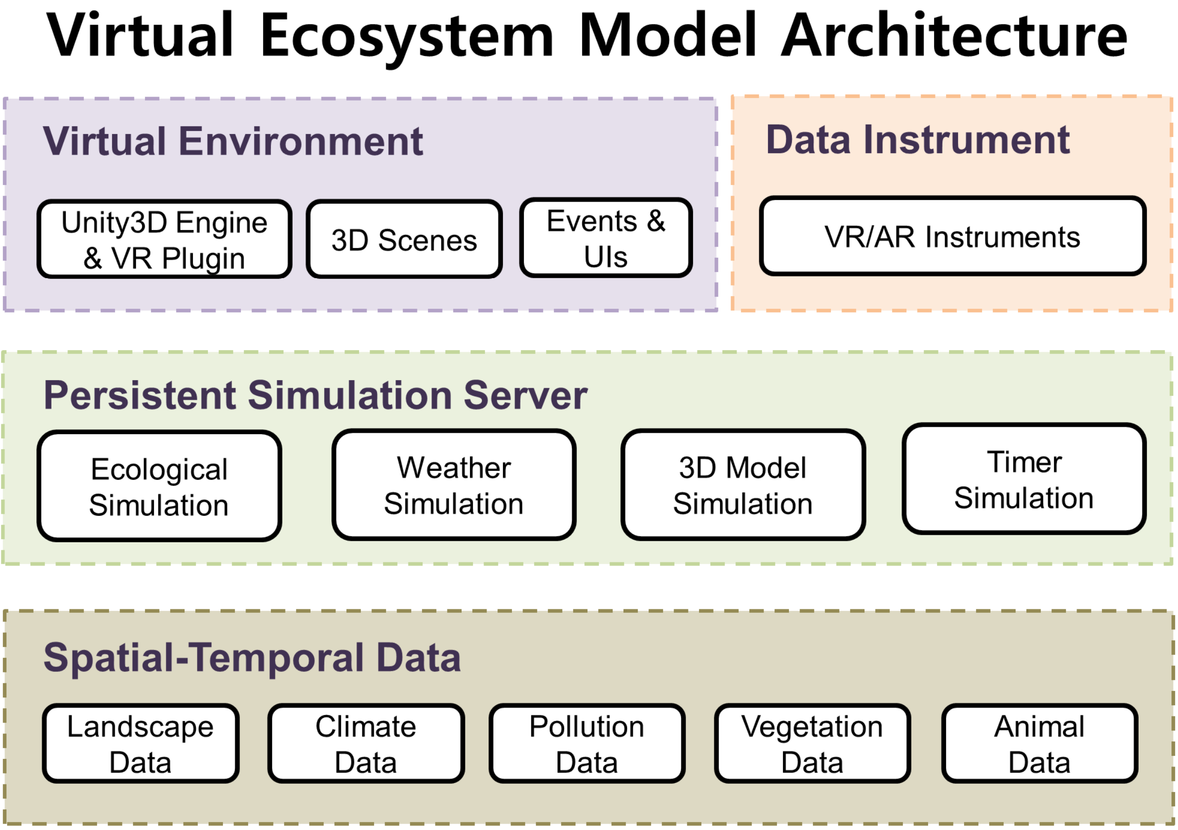

Figure 1. System architecture of virtual reality simulation based on virtual ecosystem model.

4.2. Simulation Server

In the virtual ecosystem simulation model, the server has environment configuration data as a database and provides the function capable of causality, spatiotemporal data linkage, persistent world, and data measurement. All environmental data changes in the virtual environment should be changed according to specific rules. It is best to have a scientifically based formula, such as linear, quadratic, exponential, or Gaussian. For example, it should appear as a causal connection where water and carbon dioxide react to form carbonic acid, the carbonic acid concentration of seawater rises at a certain rate, and the pH value of seawater also falls. Another example is the glacier elevation of the Antarctic and the Arctic due to global warming, resulting in a decrease in the sea ice extent, resulting in a decrease in animal populations, and a rising of sea level should be simulated.

4.3. Virtual Environment

The virtual ecosystem data are received from the server and then configured and visually displayed in the three-dimensional virtual environment to represent the virtual ecosystem. This virtual environment presents the landscape from deriving 3D modelling parameters according to different environmental factors in the virtual ecosystem. Basically, it also supports user interaction so that the user can navigate the virtual environment from a first-person point of view and the user can measure the environmental data in the virtual environment. For example, when a ray emitted from a virtual device controller hits the corresponding measurement object (data instrument), the hidden data information is displayed.

The virtual environment was implemented with Unity 3D [48] with VRTK and Steam VR plugin. In addition to Unity UI, game object, and event functions, several modules, such as database connection, networking, data script configuration, and rendering modules, were developed. The immersive virtual reality system used in this research is HTC VIVE [49]. VIVE includes two virtual base stations, two controllers, and a head mounted display (HMD). HTC VIVE's virtual base station provides room-scale tracking by building an approximately 3 m × 3 m virtual activity area that tracks the position of the user's head and controller. Therefore, in this three-dimensional virtual activity space, users can walk naturally while wearing a headset, and by using a motion tracking controller, they can naturally manipulate and accurately interact with virtual objects.

4.4. Data Instrument

Environmental monitoring is defined as "the process of continuously observing and regularly measuring environmental parameters of a specific area in order to understand a phenomenon" [9]. Environmental monitoring is important for data analysis in virtual reality or augmented reality for nature and environment. This research provides a data instrument that helps users measure, collect, and observe the simulation data, either directly in a virtual environment or using an additional mobile device to support environmental education and scientific inquiry learning. The data instrument can visualize the environmental data in the virtual environment as images or text, so that the user can observe the phenomenon via instruments. Users can enhance self-efficacy by the direct control of data instruments or watching others do it, so that they will learn environmental issues intuitively and transfer the knowledge to the real world [50].

5. Applications

In this section, we present two applications designed and developed using the immersive virtual reality simulation based on the virtual ecosystem model: Melting Sea Ice and Mission Save the Earth. The Meting Sea Ice project is an immersive virtual reality game developed to help students experience the impact on biodiversity and climate changes caused by global warming from 1950 to 2020 in Antarctica and the Arctic [30]. Mission Save the Earth is an immersive virtual reality game designed to engage students in learning pro-environmental behaviors while they directly address environmental pollution problems [45]. Table 2 shows a summary of characteristics of how the virtual ecosystem model is being applied to the application.

Table 2. Summary of characteristics of the virtual ecosystem model applied to the application.

Application	Causality	Spatial-Temporal	Data Instrument	Persistency
Melting Sea Ice VR	Antarctica and Arctic ecology by climate change	1950–2020 climate, sea ice index, biodiversity data	Timer, thermometer, CO_2 meter, O_2 meter, a glacier elevation meter, a sea ice extent meter, a sea level meter	World persistent over time
Mission Save the Earth VR	Air pollution, water pollution, soil pollution, endangered species by human behavior	Vegetables, farming, weather, pollution data	Vegetable, weather, pollution	World continue to evolve based on the last updated data

5.1. Melting Sea Ice

The Melting Sea Ice project explores global warming caused by the use of fossil fuels, the resulting disappearance of sea ice in the Antarctic and Arctic, and the huge change in the polar ecosystem. In this project, the virtual reality technology is used to supplement traditional educational methods based on books and images, and it aims to provide an immersive, tangible education about the damage to the Antarctic and Arctic environment caused by global warming from 1950 to 2020. The Sea Ice Index from the National Snow and Ice Data Center (NSIDC) was used as a data source [51].

In the Melting Sea Ice project, temporal coordinates and corresponding spatial coordinates of different eras were designed to show the Antarctic and Arctic from the 1950s to the 2020s. If the user enters different time coordinates, the spatial coordinates will also change, resulting in a different time and space experience. In addition, various data instruments are provided for users to measure environmental data in the virtual environment to recognize climate change. The user can use a thermometer (that measures the Antarctic and Arctic temperatures for the year), a carbon dioxide (CO_2) concentration meter, a glacier elevation meter, a sea ice extent meter, a sea level meter, and an ozone (O3) concentration meter.

Figures 2 and 3 show the difference between the Arctic and the Antarctic in the 1950s and the 2020s in the Melting Sea Ice project. Timer shows the time zone from 1950 to 2020, and if the user selects the desired year, he/she can “timer jump” to that Arctic virtual environment. The user can launch a virtual line by clicking VIVE controller touchpad and when the line selects the corresponding year, pressing the “trigger” of the controller moves it to the Arctic/Antarctic virtual environment of the corresponding year.

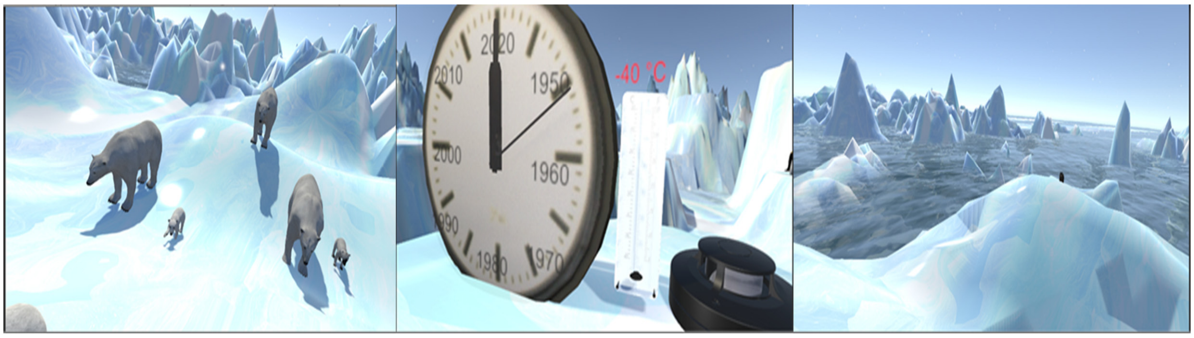

Figure 2. Arctic in the 1950s (**left**), timer, thermometer, CO_2 concentration meter data monitoring in Arctic in the 1950s (**middle**), Arctic in the 2020s (**right**).

Figure 3. Antarctic in the 1950s (**left**), timer, thermometer, CO_2 concentration meter data monitoring in the Antarctic in the 1990s (**middle**), Antarctic in the 2020s (**right**).

As the temperature rises in the Antarctic and Arctic due to global warming, the glaciers begin to melt. The Antarctic and Arctic sea ice is gradually shrinking, and the population of polar bears and various animals has declined sharply. In the past, the earth was sufficient to suppress the greenhouse effect by simply the photosynthesis of plants, but the post-industrial change has disrupted the original ecological cycle and caused severe environmental destruction due to artificial environmental factors. There is a very close relationship between the various environmental factors constituting the environment, and a change in one environmental factor has a very large effect on the other environmental factors.

By examining the reasons for the great changes in the Antarctic and Arctic over the past few decades, it is understandable that external, man-made environmental factors have invaded the polar ecosystems. Figure 4 shows the factory, such as oil refinery and automobile fume scene. With global high economic growth and rapid industrialization, more factories are being built, and factories using coal fuels emit more toxic substances, creating a greenhouse gas phenomenon. Greenhouse gases can absorb heat radiation, and many greenhouse gases accumulate more heat, forming the greenhouse effect, which causes global warming. The refrigerant scene shown in Figure 5 shows the inside of a normal house. The house has air conditioning, and the Freon gas refrigerant from the air conditioner accelerates global warming and destroys the ozone layer.

Figure 4. Causes of global warming, such as factory smoke (**left**) and automobile fumes (**right**), since industrialization in the 1970s.

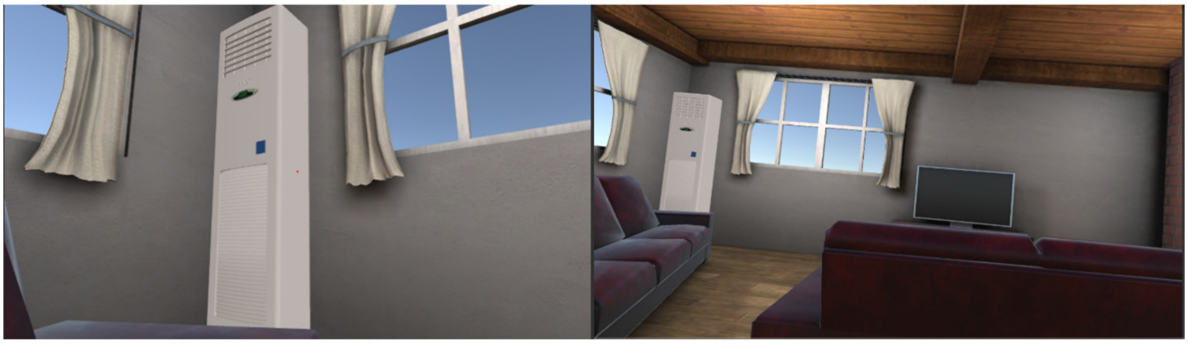

Figure 5. Causes of global warming, such as Freon gas refrigerant from the air conditioning.

5.2. Mission Save the Earth

The Mission Save the Earth project uses an immersive virtual reality technology to help students engage with environmental problems and focus on taking more active environmentally friendly behaviors with an interest in environmental protection. The project was developed based on learning materials collected from the National Environmental Education Center portal [52]. It deals with major environmental pollution, such as air pollution, water pollution, and soil pollution, as well as identifying endangered species and environmental education quizzes being offered. Using the OpenWeather API [53], the actual weather data of Seoul, Republic of Korea is retrieved and stored in the virtual ecosystem server once every 30 min. Based on the information of this virtual ecosystem, weather or environmental factors in the virtual environment are created.

The Mission Save the Earth is composed of the main house scene, the village scene, the store scene, and the quiz scene. The main house scene is the first scene that the user encounters and they can see the user manual and proceed to the login or membership registration. When the user logs in, user-related entities, such as activity coins; plant type and number; weather information; and air, soil, and water environmental pollution levels stored in the database, are retrieved, and the system is initialized for the login user. Figure 6 (left) shows that the user uses the virtual keyboard to type their name to create a login name (e.g., PARK) and a character in the main house scene. Figure 6 (right) shows the PARK user's character appearing in the room after the user completes the login. In the main house scene, the user can get instructions on the user manual for the user interface.

Figure 6. The main house scene with user login interaction (**left**), main house interior with the PARK user character (**right**).

Figure 7 shows the top-down view of the village scene. The village scene consists of a main house, an air pollution area above the factory area, a water pollution area towards a nearby stream, a separate waste collection area across the factory area, a farm area where the user can purchase seeds in the store to plant and grow crops in the garden, and the puzzles about the endangered animals scattered throughout the village.

Figure 7. The village scene consists of a main house, a store, a garden, an air pollution area, a water pollution area, a separate waste collection area, and endangered species puzzles all around in the village.

In the village, the user can fly over the factories and purify the air from the sky, as shown in Figure 8 (left). There is also water pollution in the stream near the factory area, as shown in Figure 8 (right). Users can purify water-polluting oil by absorbing it with an adsorbent. If air and water pollution are not cleaned up, farm crops will rot in two stages.

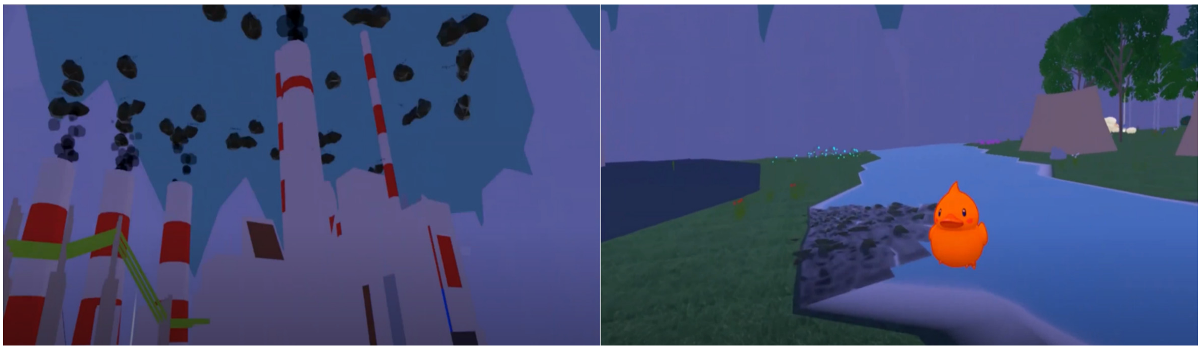

Figure 8. Cleaning air pollution (**left**) and purifying water pollution in the stream (**right**).

In addition, the user can go to the garbage collection area to prevent soil contamination and obtain fertilizer for the crops grown on the farm through garbage collection, as shown in Figure 9 (left). The user can purchase seeds and watering cans in the store next to the garden. As shown in Figure 9 (right), the user can plant the purchased seeds in a desired location of the garden and water directly with a watering can to grow crops. There are six crops (carrot, radish, eggplant, pumpkin, tomato, and turnip), and crops are grown over a total of three stages. Factors affected by crops include actual weather, watering volume, and pollution level. Each plant has a growth percentage and grows by one level at 30% and 60%. When it reaches 90%, it turns into the final crop. The plant contamination stage was set in two stages, and in the first stage, a dark material was covered to express that the plant was rotting. In the second stage, the plant rots.

Figure 9. Separate waste collection for cleaning soil pollution (**left**), and garden in the village scene (**right**).

As shown in Figure 10 (left), the user can freely move around the village to collect hidden puzzles. If the user talks to various animals (such as lambs, cows, ducks, etc.) in the village, the animals can give the user hints for the environmental education quiz, and after that the user can obtain a puzzle piece. The shape of the puzzle is endangered animals, and if all sixteen puzzle pieces are collected, one endangered animal puzzle is completed. Then, after the user receives information about the specific endangered animal, the user will take a spaceship to go to space. Then, as shown in Figure 10 (right), it moves to the quiz scene, where the user looks at the Earth from inside the spaceship. When the user clicks on the polluted area of Earth in the spaceship, a quiz related to environmental pollution appears on the computer screen of the spacecraft, and when the user solves all the problems, they get coins and go back to the village.

Figure 10. Endangered species puzzle pieces collected in the village (**left**), quiz scene (**right**).

6. Evaluation

In this section, we describe a usability study evaluated on the use of the Melting Sea Ice application. Five graduate and four undergraduate students participated where three have virtual reality experience and one has educational virtual reality experience. The participant was assigned to freely experience the Melting Sea Ice application within 5 min. After the virtual reality exposures, the participant was asked to answer questionnaires and qualitative interviews on usability (fun, immersion, satisfaction, interactivity, ease of use, and educational effect), as well as the virtual ecosystem model features.

Fun and immersion indicate how fun and immersive this VR application is, and satisfaction indicates the overall satisfaction felt while experiencing this VR application. Interactivity refers to how quickly and naturally the application responds to user interactions. Additionally, ease of use refers to how convenient the interface is to use. The educational effect indicates how much the user increases the awareness of global warming after using this VR application. Each question was answered with a score from 1 (low) to 10 (high).

Table 3 shows the average of usability evaluation results on the Melting Sea Ice application. Overall the results were low, except for educational effect. Among them, in particular, those with less fun and interactivity seem to need to be improved. As a result of the qualitative interview, most of them said this virtual reality experience was very interesting. However, many participants pointed out the lack of realism. Some also stated that the degree of freedom of interaction was low. However, all participants said that this application helped users become aware of environmental pollution and climate change in the Antarctic and Arctic from 1950 to 2020 due to global warming in a more intuitive manner. They expected a lot from using virtual reality as a new education means for environmental education. There was also an opinion that more research, such as the Melting Sea Ice application, was needed for environmental education in school.

Table 3. Average of usability evaluation on the Melting Sea Ice application.

Usability Feature	Score (1–10)
Fun	6
Immersion	7
Satisfaction	7
Interactivity	6
Ease of use	7
Educational effect	9

Table 4 shows the average of virtual ecosystem model feature evaluation results on the Melting Sea Ice application. All participants had a more intuitive understanding and awareness of the causal relationship of changes in the Arctic and Antarctic environments. There is a relatively clear recognition in the spatial-temporal data connectivity in the virtual environment. Two different opinions emerged from the data population and instrument. Users with previous VR experience said the interaction method used in this application was typical, there was no novelty, and the use of the VR controller was uncomfortable, so the usability was a little bit poor. However, for users who have no VR experience, the data instrumentation was very interesting. It seemed as if the user had become an actual Antarctic and Arctic researcher by measuring and collecting data while exploring the Antarctic and Arctic places. The persistence of the virtual environment seems somewhat lacking, since it only represented the persistence of the world over a period of time.

Table 4. Average of virtual ecosystem model evaluation on the Melting Sea Ice application.

Virtual Ecosystem Model Feature	Score (1–10)
Causality	10
Spatial-temporal data	8
Data population and instrument	7
Persistent world	7

7. Conclusions and Future Directions

Climate change and global warming are perhaps the most urgent global issues. Recently, environmental research is being actively conducted around the world led by biology, marine biology, climatology and engineering. The development of virtual reality or augmented reality applications for environmental education has also begun to be popular. However, environmental education requires a different approach from traditional science and engineering education. This is because it should not only convey knowledge to learners but also the need to influence their attitudes and behaviors. Environmental education should allow users to properly recognize environmental issues. It should also equip students with the necessary knowledge and attitudes for environmental preservation and help them actively participate in solving environmental problems.

Recently, various natural disasters caused by climate change have made people more aware of the seriousness of the environmental problem, but it is easy to overlook the importance of environmental education because they cannot immediately see the impact of their actions on the environment in real life. Virtual reality can easily control variables that are difficult to control in real life and can arouse interest by providing appropriate interactions to users. In particular, virtual reality provides users with a controlled simulation suitable for teaching about environmental problems caused by various factors. The goal of this research was to develop an immersive virtual reality simulation designed to recognize the importance of environmental education and engage users in environmentally friendly behavior.

In this research, we presented the analysis of the virtual ecosystem model and the implementation of immersive virtual reality simulation based on the virtual ecosystem model. The virtual ecosystem model has characteristics in which causality between environmental factors are established, environmental factors are interactively linked to spatial and temporal fluctuations, environmental factors are measured using instruments, and a persistent environmental state is maintained by establishing causality. The simulation consists of simulation data, simulation server, virtual environment, and data instrument. It is designed to allow students to directly experience the seriousness of environmental problems and interactively manipulate the environmental factors, which will affect the environment. The evaluation of this simulation showed a positive effect in which participants said that they understood the environmental changes caused by global warming more intuitively. However, the usability results are not sufficient enough to draw conclusions, since the number of participants was small.

According to the current condition of global warming and climate change, more research on immersive virtual reality simulation for environmental education will have to be continued. A virtual reality experiential approach helps to teach students the necessity and effectiveness of environmental education and helps to modify their attitudes in support of pro-environmental behaviors. An immersive virtual reality simulation would never exist as a learning environment without applying pedagogy. In future studies, we plan to conduct a systematic usability study of students in school to see if this simulation is effective in environmental education by supplementing the traditional school environmental education and increasing immersion. Based on the results obtained through the usability evaluation, we intend to improve the pedagogy and the system architecture of this simulation. In addition, we plan to enhance the virtual ecosystem model in order to support cooperative education of multiple users and support user interactions on the simultaneous use of virtual reality and augmented reality.

Author Contributions: Conceptualization, K.S.P. and Y.C.; methodology, K.S.P. and Y.C.; software, K.S.P.; validation, K.S.P.; formal analysis, K.S.P.; investigation, K.S.P.; resources, K.S.P.; data curation, K.S.P.; writing—original draft preparation, K.S.P. and Y.C.; writing—review and editing, K.S.P. and Y.C.; visualization, K.S.P. and Y.C.; supervision, K.S.P.; project administration, K.S.P.; funding acquisition, K.S.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no extra funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Queiroz, A.C.; Kamarainen, A.M.; Preston, N.D.; Leme, M.C. Immersive Virtual Environments and Climate Change Engagement. *Immersive Learn. Res. Netw.* **2018**, *153*, e164.
2. Fan, S.; Zhang, Y.; Fan, J.; He, Z.; Chen, Y. The Application of Virtual Reality in Environmental Education: Model Design and Course Construction. In Proceedings of the 2010 International Conference on Biomedical Engineering and Computer Science, Wuhan, China, 23–25 April 2010; pp. 1–4. [CrossRef]
3. Hamilton, D.; McKechnie1, J.; Edgerton, E.; Wilson, C. Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *J. Comput. Educ.* **2021**, *8*, 1–32. [CrossRef]
4. Pirker, J.; Dengel, A. The Potential of 360 Virtual Reality Videos and Real VR for Education—A Literature Review. *IEEE Comput. Graph. Appl.* **2021**, *41*, 76–89. [CrossRef] [PubMed]
5. Tan, Q.P.; Huang, L.; Xu, D.; Cen, Y.; Cao, Q. Serious Game for VR Road Crossing in Special Needs Education. *Electronics* **2022**, *11*, 2568. [CrossRef]
6. Markowitz, D.; Bailenson, J. Virtual Reality and The Psychology of Climate Change. *Curr. Opin. Psychol.* **2021**, *42*, 60–65. [CrossRef]
7. Rambach, J.; Lilligreen, G.; Schäfer, A.; Bankanal, R.; Wiebel, A.; Stricker, D. A survey on applications of augmented, mixed and virtual reality for nature and environment. In *International Conference on Human-Computer Interaction*; Springer: Cham, Switzerland, 2021; pp. 653–675. [CrossRef]
8. Wally, G.; Bertoni, M.; Graziosi, S.; Ferrise, F. Exploring the Use of Virtual Reality to Support Environmentally Sustainable Behavior: A Framework to Design Experiences. *Sustainability* **2021**, *13*, 943. [CrossRef]
9. Veas, E.; Grasset, R.; Ferencik, I.; Grünewald, T.; Schmalstieg, D. Mobile augmented reality for environmental monitoring. *Pers. Ubiquitous Comput.* **2013**, *17*, 1515–1531. [CrossRef]
10. Studer, C.; Shave, J. Water in augmented space. In Proceedings of the 2011 IEEE International Symposium on Mixed and Augmented Reality-Arts, Media, and Humanities, Basel, Switzerland, 26–29 October 2011; pp. 103–104. [CrossRef]
11. West, R.; Margolis, T.; O'Neil-Dunne, J.; Mendelowitz, E. MetaTree: Augmented reality narrative explorations of urban forests. In *The Engineering Reality of Virtual Reality 2012*; SPIE: Bellingham, WD, USA, 2012; Volume 8289. [CrossRef]
12. West, R.; Halley, A.; O'Neil-Dunne, J.; Gordon, D.; Pless, R. Collaborative imaging of urban forest dynamics: Augmenting re-photography to visualize changes over time. In *The Engineering Reality of Virtual Reality 2013*; SPIE: Bellingham, WD, USA, 2013; Volume 8649. [CrossRef]
13. Frajberg, D.; Fraternali, P.; Torres, R.N. Heterogeneous Information Integration for Mountain Augmented Reality Mobile Apps. In Proceedings of the 2017 IEEE International Conference on Data Science and Advanced Analytics, Tokyo, Japan, 19–21 October 2017; pp. 313–322. [CrossRef]
14. Santos, B.; Romão, T.; Dias, A.E.; Centieiro, P.; Teixeira, B. Changing Environmental Behaviors through Smartphone-Based Augmented Experiences. In *International Conference on Advances in Computer Entertainment Technology*; Nijholt, A., Romão, T., Reidsma, D., Eds.; Springer: Berlin/Heidelberg, Germany, 2012. [CrossRef]
15. Nim, H.T.; Wang, M.; Zhu, Y.; Sommer, B.; Schreiber, F.; Boyd, S.E.; Wang, S. Communicating the Effect of Human Behaviour on the Great Barrier Reef via Mixed Reality Visualization. In Proceedings of the 2016 Big Data Visual Analytics (BDVA), Sydney, NSW, Australia, 22–25 November 2016; pp. 1–6. [CrossRef]
16. McGinity, M. Immersive Media for Environmental Awareness. In Proceedings of the 2018 IEEE Workshop Augmented Virtual Realities Good (VAR4Good), Reutlingen, Germany, 18 March 2018; pp. 1–5. [CrossRef]

17. Ke, P.; Keng, K.-N.; Jiang, S.; Cai, S.; Rong, Z.; Zhu, K. Embodied Weather: Promoting Public Understanding of Extreme Weather Through Immersive Multi-Sensory Virtual Reality. In Proceedings of the VRCAI '19: 17th International Conference on Virtual-Reality Continuum and its Applications in Industry, Brisbane, QLD, Australia, 14–16 November 2019; Voluem 60, pp. 1–2. [CrossRef]
18. Huang, J.; Lucash, M.S.; Scheller, R.M.; Klippel, A. Visualizing Ecological Data in Virtual Reality. In Proceedings of the 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka, Japan, 23–27 March 2019; pp. 1311–1312. [CrossRef]
19. Huang, J.; Lucash, M.S.; Simpson, M.B.; Helgeson, C.; Klippel, A. Visualizing Natural Environments from Data in Virtual Reality: Combining Realism and Uncertainty. In Proceedings of the 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Osaka, Japan, 23–27 March 2019; pp. 1485–1488. [CrossRef]
20. Torres, N.G.; Campbell, P.E. Aire: Visualize air quality. In Proceedings of the ACM SIGGRAPH 2019 Apply Hour (SIGGRAPH '19), Los Angeles, CA, USA, 28 July–1 August 2019; pp. 1–2. [CrossRef]
21. Ramachandran, G.S.; Bogosian, B.; Vasudeva, K.; Sriramaraju, S.I.; Patel, J.; Amidwar, S.; Malladi, L.; Shylaja, R.D.; Kumar, N.R.B.; Krishnamachari, B. Demo: An Immersive Virtualization of Micro-climate Data using USC Air. In Proceedings of the MobiSys '19: Proceedings of the 17th Annual International Conference on Mobile Systems, Applications, and Services, Seoul, Republic of Korea, 17–21 June 2019.
22. Windschitl, M.; Winn, W. A Virtual Environment Designed to Help Students Understand Science. In *Fourth International Conference of the Learning Sciences*; Psychology Press: London, UK, 2000; pp. 290–296.
23. Dede, C.; Grotzer, T.A.; Kamarainen, A.; Metcalf, S. EcoXPT: Designing for Deeper Learning through Experimentation in an Immersive Virtual Ecosystem. *J. Educ. Technol. Soc.* **2017**, *20*, 166–178.
24. Kamarainen, A.; Reilly, J.; Metcalf, S.; Grotzer, T.; Dede, C. Using Mobile Location-Based Augmented Reality to Support Outdoor Learning in Undergraduate Ecology and Environmental Science Courses. *Bull. Ecol. Soc. Am.* **2018**, *99*, 259–276. [CrossRef]
25. Srisuphab, A.; Silapachote, P.; Sirilertworakul, N.; Utara, Y. Integrated ZooEduGuide with multimedia and AR from the largest living classrooms to wildlife conservation awareness. In Proceedings of the TENCON 2014—2014 IEEE Region 10 Conference, Bangkok, Thailand, 22–25 October 2014; pp. 1–4. [CrossRef]
26. Theodorou, P.; Kydonakis, P.; Botzori, M.; Skanavis, C. Augmented Reality proves to be a breakthrough in environmental education. *Conf. Prot. Restor. Environ.* **2018**, *7*, 219–228.
27. Clayborn, J.; Delamarre, A.P. Living room conservation: A virtual way to engage participants in insect conservation. *Rethink. Ecol.* **2019**, *4*, 31–43. [CrossRef]
28. Mawsally, D.A.; Sudarmilah, E. A Virtual-Reality Edu-Game: Save The Environment from the Dangers of Pollution. *Khazanah Inform. J. Ilmu Komput. Dan Inform.* **2019**, *5*, 140–145. [CrossRef]
29. Taulien, A.; Paulsen, A.; Streland, T.; Jessen, B.; Wittke, S.; Teistler, M. A Mixed Reality Environmental Simulation to Support Learning about Maritime Habitats: An Approach to Convey Educational Knowledge With a Novel User Experience. In *Proceedings of Mensch und Computer 2019*; ACM: New York, NY, USA, 2019; pp. 921–925. [CrossRef]
30. Liu, H.; Park, K.S. A Virtual Reality Exploration to the Artic and the Antarctic for Climate Change Lesson. In *Proceedings of the Korea Information Processing Society Conference*; Korea Information Processing Society: Seoul, Korea, 2020; pp. 1115–1117. [CrossRef]
31. Sermet, Y.; Demir, I. GeospatialVR: A web-based virtual reality framework for collaborative environmental simulations. *Comput. Geosci.* **2022**, *159*, 105010. [CrossRef]
32. Winn, W.; Stahr, F.; Sarason, C.; Fruland, R.; Oppenheimer, P.; Lee, Y.-L. Learning Oceanography from a Computer Simulation Compared with Direct Experience at Sea. *J. Res. Sci. Teach.* **2006**, *43*, 25–42. [CrossRef]
33. Bailey, J.O.; Bailenson, J.N.; Flora, J.; Armel, K.C.; Voelker, D.; Reeves, B. The Impact of Vivid Messages on Reducing Energy Consumption Related to Hot Water Use. *Environ. Behav.* **2015**, *47*, 570–592. [CrossRef]
34. Fonseca, D.; Kraus, M. A comparison of head-mounted and hand-held displays for 360° videos with focus on attitude and behavior change. In Proceedings of the 20th International Academic Mindtrek Conference (*AcademicMindtrek*'16), Tampere, Finland, 17–18 October 2016; pp. 287–296. [CrossRef]
35. Tudor, A.; Minocha, S.; Collins, M.; Tilling, S. Mobile virtual reality for environmental education. *J. Virtual Stud.* **2018**, *9*, 25–36.
36. Hsu, W.-C.; Tseng, C.-M.; Kang, S.-C. Using Exaggerated Feedback in a Virtual Reality Environment to Enhance Behavior Intention of Water-Conservation. *Educ. Technol. Soc.* **2018**, *21*, 187–203.
37. Markowitz, D.M.; Laha, R.; Perone, B.P.; Pea, R.D.; Bailenson, J.N. Immersive virtual reality field trips facilitate learning about climate change. *Front. Psychol.* **2018**, *9*, 2364. [CrossRef]
38. Ritter, K.A., III; Stone, H.; Chambers, T.L. Chambers, Empowering Through Knowledge: Exploring Place-based Environmental Education in Louisiana Classrooms Through Virtual Reality. *Comput. Educ. J.* **2019**, *10*, 1–7.
39. Chang, S.-C.; Hsu, T.-C.; Jong, M.S.-Y. Integration of the peer assessment approach with a virtual reality design system for learning earth science. *Comput. Educ.* **2020**, *146*, 103758. [CrossRef]
40. Chirico, A.; Scurati, G.W.; Maffi, C.; Huang, S.; Graziosi, S.; Ferrise, F.; Gaggioli, A. Designing virtual environments for attitudes and behavioral change in plastic consumption: A comparison between concrete and numerical information. *Virtual Real.* **2020**, *25*, 107–121. [CrossRef]
41. Fokides, E.; Chachlaki, F. 3D Multiuser Virtual Environments and Environmental Education: The Virtual Island of the Mediterranean Monk Seal, Technology. *Knowl. Learn.* **2020**, *25*, 1–24. [CrossRef]

42. Nelson, K.M.; Anggraini, E.; Schlüter, A. Virtual reality as a tool for environmental conservation and fundraising. *PLoS ONE* **2020**, *15*, e0223631. [CrossRef]
43. Petersen, G.B.; Klingenberg, S.; Mayer, R.E.; Makransky, G. The Virtual Field Trip: Investigating how to optimize immersive virtual learning in climate change education. *Br. J. Educ. Technol.* **2020**, *51*, 2099–2115. [CrossRef]
44. Ruan, B. VR-Assisted Environmental Education for Undergraduates. *Adv. Multimed.* **2022**, *2022*, 3721301. [CrossRef]
45. Park, J.H.; Boo, J.H.; Park, K.S. Design and Development of an Immersive Virtual Reality Simulation for Environmental Education. *J. Korea Inst. Inf. Commun. Eng.* **2022**, *26*, 541–547. [CrossRef]
46. Ramasundram, V.; Grunwald, S.; Mangeot, A.; Comerford, N.B.; Bliss, C.M. Development of an environmental virtual field laboratory. *Comput. Educ.* **2005**, *45*, 21–34. [CrossRef]
47. Steffen, J.H.; Gaskin, J.E.; Meservy, T.O.; Jenkins, J.L.; Wolman, I. Framework of Affordances for Virtual Reality and Augmented Reality. *J. Manag. Inf. Syst.* **2019**, *36*, 683–729. [CrossRef]
48. Unity3D. Available online: https://unity.com/ (accessed on 30 December 2022).
49. HTC VIVE. Available online: https://www.vive.com/ (accessed on 30 December 2022).
50. Lee, T.; Wen, Y.; Chan, M.Y.; Azam, A.B.; Loos, C.K.; Taib, S.; Ooi, C.H.; Huang, H.; Xie, Y.; Cai, Y. Investigation of virtual & augmented reality classroom learning environments in university STEM education. *Interact. Learn. Environ.* **2022**, 1–16. [CrossRef]
51. Sea Ice Index, Version 3 (G02135), National Snow and Ice Data Center. Available online: https://nsidc.org/data/g02135/versions/3 (accessed on 30 December 2022).
52. National Environmental Education Center. Available online: https://www.keep.go.kr/ (accessed on 30 December 2022).
53. OpenWeather API. Available online: https://openweathermap.org/api (accessed on 30 December 2022).