Learning About Environmental Issues With A Desktop Virtual Reality Field Trip

Alec Bodzin[1], Robson Araujo-Junior[1], Chad Schwartz[2], David Anastasio[1], Thomas Hammond[1], and Brian Birchak[2]

Lehigh University[1] and Lehigh Gap Nature Center[2]

Paper presented at the 2022 Association for Science Teacher Education (ASTE) Annual Meeting in Greenville, SC.

Keywords: virtual reality, field trip, environmental issues, place-based pedagogy

Program Abstract

A design partnership with informal environmental educators developed a desktop virtual reality field trip (dVFT) to learn about an environmental issue and was implemented in a course with preservice and inservice science teachers. Implications for science teacher educators interested in developing a dVFT are presented.

Proceedings Abstract

This innovations paper describes a design partnership with university faculty and informal environmental educators that developed a desktop virtual reality field trip (dVFT) to learn about the environmental changes leading to a Superfund designation that occurred during the past two centuries as a result of a zinc smelting plant operation in our watershed. The Lehigh River watershed is quite unique since it was a driving force of the industrial revolution in the United States during the 19th century and thus has broad appeal to those living in other geographic locations. We provide background on place-based learning and the affordances that virtual reality (VR) and VR field trips can provide for learning. We describe our design and development approach and present the resulting dVFT. We discuss how the dVFT was used in an environmental education course during a global pandemic. The course included preservice and inservice secondary science teachers. The students experienced both immersion and presence when using the dVFT, which served two main purposes in the course. Firstly, it provided students who were unable to attend the optional field trip with a meaningful experience to learn about an important environmental issue and remediation process. Secondly, the dVFT served as a valuable foundational learning activity for students to familiarize themselves with the actual field site prior to going to the physical site location. Implications for science teacher educators interested in developing a dVFT are discussed.

Introduction

Developing skills for understanding and addressing environmental issues is a key component of environmental literacy and is advocated by both the Association for Science Teacher Education and the North American Association for Environmental Education as an essential component of preparing preservice teachers (Association for Science Teacher Education, n.d.; North American Association for Environmental Education, 2017). Furthermore, understanding human impacts on Earth systems, such as damaging or destroying natural habitats, is a disciplinary core idea in the Next Generation Science Standards (NGSS Lead States, 2013). At our institution, the first author has taught an environmental education course for many years. Typically, about half of the students enrolled in this course are preservice and inservice secondary science teachers (grades 7-12).

The course focuses on pedagogical approaches for teaching and learning. A significant amount of course content focuses on environmental issues primarily in our local watershed, the Lehigh River watershed in Pennsylvania, USA. Watersheds have wide-ranging impacts on environmental protection, policy, and on everyday life (as everyone lives in a watershed). The watershed is a powerful area of study that can both educate and motivate people of all ages to engage in environmentally responsible behaviors that impact all of humanity (Shepardson et al., 2007). Our watershed is quite unique since it was a driving force of the industrial revolution in our country during the 19th century. The availability of anthracite coal, zinc, and other minerals, coupled with access to the Lehigh River, which provided a major transportation route via canals and railway routes, helped revolutionize transportation, industry, and business in the United States (Fox, 2019). Products that were manufactured within our watershed include steel, cement, iron, rolled zinc, zinc oxide, and other materials. The by-products from the manufacturing processes placed many harmful pollutants in our watershed, causing significant environmental degradation. Therefore, the rich industrial history of the Lehigh River watershed makes it appealing to learn about environmental issues and remediation not only for those who reside in the watershed but also by others throughout the United States.

A local watershed is a geographically familiar setting for students that is easily accessible for daylong field trips. This is true for the students enrolled in the course as well as for the students of the inservice science teachers who take the course. Studying local environmental issues provides learners with opportunities to experience science learning with meaningful contexts. In addition to understanding underlying science, investigating environmental issues and their solutions actively involves learners in practicing and improving skills, including critical reflection, problem-solving, and decision making, which are inherently important skills to science teacher education programs (Bodzin, 2010).

One of the challenges that occurs in the course each year is that there are always a few students who are unable to attend a Saturday field trip. It is logistically impossible for students to make up a field trip if they are absent. To address this issue, we established a design partnership with the Lehigh Gap Nature Center to develop a desktop virtual reality field trip (dVFT) that could serve as a make-up experience for a missed course field trip or as a means for secondary age students and the general public to learn about the environmental changes at the Lehigh Gap in Pennsylvania, USA.

In this article, we begin by providing background on place-based learning and the affordances that virtual reality (VR) and VR field trips can provide for learning. We then describe our design and development approach and describe the dVFT. We discuss how the dVFT was used in the course during spring 2021, a time of global pandemic. Due to university

COVID-19 restrictions, only an optional course field trip to the Lehigh Gap could be offered. We then discuss the effectiveness of using a dVFT and implications for science teacher educators. All co-authors collaborated on the design and development of the dVFT. The first author is a science teacher educator who taught the environmental education course where the dVFT was implemented. The second author is a graduate student and a lead developer of the dVFT. The fourth author is social studies teacher educator and the fifth author is an Earth and environmental scientist at our institution. The third author is the Director of Science and Education and the sixth author is the Director of Communications at the Lehigh Gap Nature Center.

Place-based Learning

An integral part of the environmental education course involves the pedagogical approach of place-based learning. In place-based learning, learners explore an environment outside the classroom with authentic experiences. This enables them to connect to a site, developing a sense of place (Langran & DeWitt, 2020; Semken et al., 2017; Sobel, 2004). For environmental education, environmental science, geology, and ecology learning, place-based education often involves participation in site-based learning experiences. Past studies have shown that such experiences can improve students' environmental attitudes, values, and knowledge (Alon & Tal, 2015; Dale et al., 2020; Orion & Hofstein, 1991, 1994; Semken et al., 2017). Place-based investigations can provide preservice and inservice teachers with opportunities to apply their content knowledge to familiar places in their local environment or in other geographic locations that learners may not be familiar with. This provides multiple opportunities to connect a variety of disciplines, environmental concepts, and concerns to the learners (Sarkar & Frazier, 2010; Thomas, 2020).

In some of our own university courses and public outreach programs, we have found that using place-based pedagogy with outdoor field settings was successful in promoting awareness and knowledge of environmental issues. Combining field trips to selected sites with environmental issues and focusing on case studies of those locations are some of the learning experiences we have found to be most effective. In addition, place-based approaches can have a strong effect on the students' outcomes, promoting a sense of environmental stewardship, and fostering better environmental behavior (Bodzin, 2008; Fisman, 2005, Sobel, 2004).

Affordances of Virtual Reality

Place-based learning includes both physical settings (e.g., an outdoor environmental education center) and virtual spaces (e.g., Web-based environments with virtual reality). Sociocultural perspectives argue that the features, materials, and activities associated with specific places influence learning processes and outcomes. The use of VR artifacts that mediate learning and desired performance in specific contexts and places is regarded as a "practice turn" in human learning, development, and performance (Jessor, 1996; Lave & Wenger, 1991; Rogoff, 2003; Shweder, 1996). Artifacts play an important role in distributed cognition for both interaction with individuals and with groups (Hutchins, 1995). The VR learning materials constitute the foundational resources through which people individually and collectively engage in the learning activities.

VR technologies have rapidly emerged at home and in educational settings (Merchant et al., 2014) due to their lower cost and greater availability. They are interactive computer-generated experience that takes place within a simulated environment using a personal computer or head-mounted display (also referred to as an HMD) to generate realistic images and sounds, along with handheld controllers that allow interactivity to simulate a user's physical presence in a two or three-dimensional virtual environment. VR enables its users to move and look around in an artificial world and interact with virtual features and items. This mechanism offers learners an active experience, rather than a passive one, while providing them immersion through immediate learner engagement. VR environments can be designed and developed to provide a novel learning experience to help people understand complex concepts (e.g., effects of anthropogenic impacts in a watershed), and develop important skills (e.g., observe and analyze temporal changes in a watershed). In this setting, authentic imagery, content, data, animations, video, and narration can be incorporated to provide users with an enhanced learning experience. VR can promote science learning due to its immersive nature, interactivity, authentic feeling of realism, and customizability of the environment. VR experiences can allow learners to examine science and environmental phenomena at multiple levels and at their own pace.

Most published research in the area of VR with HMDs has focused on design elements for developing immersion and a sense of presence (Jensen & Konradsen, 2018). Immersion is the level of sensory fidelity that a VR system provides and describes the experience of using VR technology (Slater, 2003). This technology works by exchanging sensory input from reality with digitally generated sensory input, such as images and sounds (Freina & Ott, 2015). Spatial immersion occurs when one feels the simulated world is perceptually convincing; it looks "authentic" and "real," and the learner feels that they are actually "there" (Jennett et al., 2008). Presence is a user's subjective psychological response to a VR system, where the user responds to the VR environment as if it were real (Sanchez-Vives & Slater, 2005).

Virtual Reality Field Trips

A VR field trip presents several characteristics of great appeal to learners and can be an enhancement to a university course, an informal education center, or for home learning when a physical location might be closed or inaccessible. For both university instructors and secondary science teachers, VR field trips have emerged as viable alternatives to regular field trips. They are less expensive, they do not involve dangerous and costly transportation or time away from the classroom, and they minimize administrative logistics for planning (Adedokun, 2012; Dolphin, 2019). In addition, a VR field trip is not affected by poor weather conditions. VR field trip features such as active control of the user experience, naturalistic, yet safe environments, and realistic representation of real-world situations may increase engagement and learning. In university science courses, Litherland and Stott (2012) found increased student participation in classes when dVFTs were implemented and Clary and Wandersee (2010) reported that students perceived that dVFTs had enhanced their science course work content understandings.

A VR field trip experience provides a sense of authentic immersion and presence, of being physically at specific geographic locations that may be either inaccessible (in time or space) or problematic (dangerous) (Jennett et al., 2018). Furthermore, a VR field trip can be designed to focus users' attention on the learning tasks. In a VR field trip environment, narration, authentic imagery, content, animations, and data can be incorporated to provide learners with a highly immersive learning experience. Since VR field trip technology allows for such supports in an immersive environment, it can be designed to provide improved access to environmental-related content for those with mobility disabilities or who are physically unable to visit an outdoor location.

VR field trips can take a variety of forms. Some are highly structured with a specific sequence of designated locations at each site and include text, audio, or other media describing specific features of that particular location. VR field trips can include 360° images or videos of a specific location where a user can pan around the environment in any direction – up, down, right, or left – and also zoom into points of interest within the immersive media. In a dVFT, Web-based 360° tours can offer a sense of agency through the ability of changing one's perspective. Moving one's head moves the camera around and allows the user to explore a place through a 360° view without physical movement (Klippel et al., 2019). Other VR field trips may be more exploratory, including only a few locations or points of interest to attract learners' attention where one has the freedom to explore by panning and zooming at their own pace (Dolphin, 2019).

There are some limitations with using a dVFT for a field trip experience. Compared with a physical site visit, dVFT activities cannot reproduce the discourse or social interactions that occur with a university instructor or an educator with particular expertise at a field site. In addition, a dVFT is not able to replicate the genuine perceptions that students would experience at an actual site. These include smells and the physical feelings of one's body in that particular space such as picking up and holding a piece of anthracite coal on a trail. Compared with using an HMD for a VR field trip, Klippel et al. (2019) contend that a dVFT with its mouse and keyboard interface does not promote a sense of embodiment or provide the same agency of mobility and situatedness that a more immersive VR field trip with an HMD can provide. This view informed our design work to provide learning experiences that support immersion.

Design and Development of the Virtual Reality Field Trip

Our project employed a design partnership with an Earth and environmental scientist, science and social studies education professors with expertise in environmental curriculum development and instructional design, and environmental educators who work with learners of all ages to promote awareness of environmental issues at the Lehigh Gap. We set a goal to develop a VR field trip that could be used in both our university courses and for education programs and community outreach for the Lehigh Gap Nature Center. We envisioned creating both a dVFT and a version that could be used with HMDs. Due to the COVID-19 pandemic, we decided to focus solely on the dVFT and revisit an HMD version at a later date. For the environmental education course, the VR field trip would serve as a pre-virtual trip visit to the Lehigh Gap prior to the actual field trip and would also provide an alternative experience for students who were unable to attend the actual site field trip. The Lehigh Gap Nature Center staff would make the dVFT accessible to the public via their Website, so anyone with internet access could virtually experience the Lehigh Gap. They also envisioned sharing it with school groups prior to an in-person visit so program participants would have a general understanding of the Lehigh Gap story before they experience the actual location; this would allow the staff to add more depth to the content that is covered in person, since program participants would already have a baseline knowledge on the history and ecology of the site.

Our design and development goal was for the dVFT to enable people to understand the environmental changes that occurred in the Lehigh River watershed in Pennsylvania during the past two centuries as a result of a zinc smelting plant operation at the Lehigh Gap. A green mountain ridge became a barren "moonscape" as a result of zinc smelting activities that began in the 1890s. The smelting plant emitted approximately 3,450 pounds of sulfur per hour from 1918 to 1970, along with heavy metals, into the atmosphere (Bleiwas & DiFrancesco, 2010). Smelter emissions produced acid rain, which spread over the surrounding landscape. Five years after the smelting plants ceased operations, a comprehensive and laborious revegetation project was initiated by the U.S. Environmental Protection Agency (EPA) and a local community group. The Lehigh Gap is revitalized today through a mixture of warm-season grasses that have trapped the heavy metals in the soil. Today, the site includes a 756-acre wildlife refuge and the Lehigh Gap

Nature Center, which is used for education, research, and outdoor recreation. The dVFT tells this story through immersive experiences.

We wanted to ensure that the dVFT would be engaging for a wide range of people from middle school age students through adult learners. We created an initial storyboard of key topics that the VR field trip would focus on. These topics included the geography of the Lehigh Gap, the role of geography in establishing the Gap as a major transportation corridor during the industrial revolution, the importance of anthracite coal to the region for manufacturing processes, the establishment of the New Jersey Zinc Company smelting plant at the Lehigh Gap (as well as the corresponding establishment of the town of Palmerton), the role of zinc ore in producing a wide range of goods, environmental degradation (specifically, how a pristine mountain became a barren "moonscape" from the acid rain that resulted from the zinc extraction and smelting processes), the establishment of the area as an Environmental Protection Agency (EPA) Superfund site, the revegetation process that occurred by creating test plots of different grass and fertilizers mixes, and the resulting primary succession and biotic diversity that occurred in the area.

Our main design idea was to create a virtual hike on a trail at the Lehigh Gap. The trail would have a number of stops that would focus on the content. Each stop would include a 360° photosphere where users could visually explore a particular location and learn about a topic area. We envisioned populating each photosphere with historical imagery provided by the Lehigh Gap Nature Center and embedded interpretative signs that were developed by the Delaware & Lehigh National Heritage Corridor that are actually on the trails. We also wanted users to get a sense of the geology that one experiences while hiking on the trail. For example, part of the trail was a railway that carried anthracite coal and other minerals. When walking on the trail, hikers can pick up and hold rocks that had years ago fallen off a train. We also wanted to include a simple animation in the VR field trip that would convey how the zinc processing plant emitted sulfur dioxide, which thereby produced acid rain, denuded the mountain, and affected the plant and animal life.

After creating an initial storyboard for the virtual hike, we asked three area middle school teachers what they thought of the idea. From these discussions, they noted that we should create an avatar to serve as a narrative guide for the VR experience. As a result of this feedback, an avatar, a bird named Brownie, was created to provide narration along the VR field trip. The focus group of teachers also felt that the VR experience should have some things for the students to actually do within each photosphere. From this feedback, we developed a task checklist that would need to be completed in each photosphere before the user could move on to the next photosphere on the virtual hike.

Photos were taken along a Lehigh Gap trail with a 360° camera on a tripod that was available to us from our university. We used the Unity game engine (see unity.com) to develop the VR experience and enabling us to include some interactive elements in the dVFT. In addition, Unity has a weather asset called UniStorm that we were able to incorporate into the experience to help convey the process of having acid rain denude the mountain. Unity is freely available to academic institutions. To assist with development, we partnered with our university's technology entrepreneurship program where a team of undergraduate students worked with us on the prototype. We then partnered with our university's computer science and engineering capstone program to recruit a team of undergraduate students to continue the project development as part of their undergraduate capstone project. The initial prototype was reviewed by a group of ten people that included non-formal STEM educators, classroom teachers, and graduate and undergraduate students with experience in VR development. The feedback was very positive and some additional minor modifications to the interface were made.

The Lehigh Gap Story

The Lehigh Gap Story is the resulting dVFT and can be used with the Firefox or Chrome Web browser. It is available at https://vrwatershed.lehigh.edu/LehighGapStory/. The landing screen presents two distinct experiences to select from: Story Mode and Exploration Mode (Figure 1). In Story Mode, avatar bird Brownie guides the user through a sequence of seven photospheres using audio narration and subtitles. In Exploration Mode, a trail map allows users to navigate through the trail pathway (Figure 2), and users can freely explore each photosphere and the media assets.

In each photosphere, there is a checklist in the upper right corner of the viewing area that users must complete before moving on to the next photosphere. Figure 3 shows an image when the user enters the first photosphere. Brownie prompts the user to click on her. This starts the narration. Alternatively, one can also “talk to Brownie” by pressing the “T” key on the keyboard. A series of images related to Brownie’s content are displayed while she talks (see Figure 4). In the first photosphere, users must listen to Brownie’s introduction to the area and also view the interpretive sign before a green arrow will appear to let them continue to the next photosphere on the trail. Brownie also prompts the user in each photosphere to complete each task on the checklist. Figure 5 shows an image of Brownie prompting the user to click on the green arrow to continue down the trail to the next photosphere. Note that the checklist in the upper right corner is completed.

Figure 1. Landing page of The Lehigh Gap Story.

Figure 2. The trail map in Exploration mode. Placing a cursor over a location site displays the site's main content.

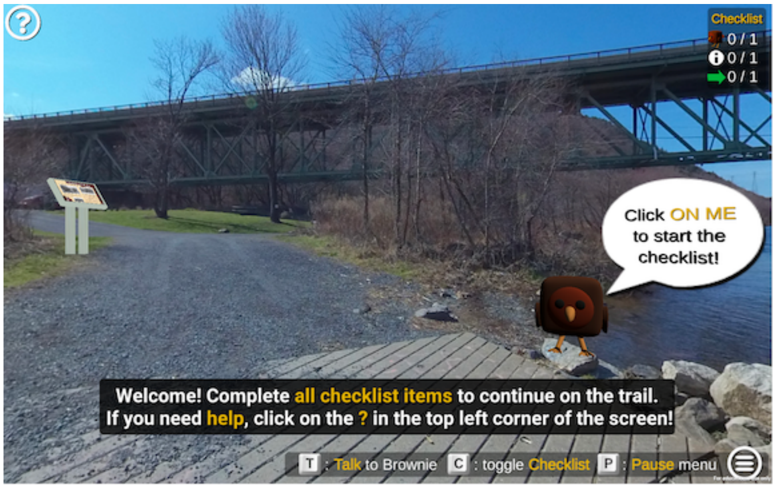

Figure 3. Image of the first photosphere. The checklist is displayed in the upper right hand corner of the screen.

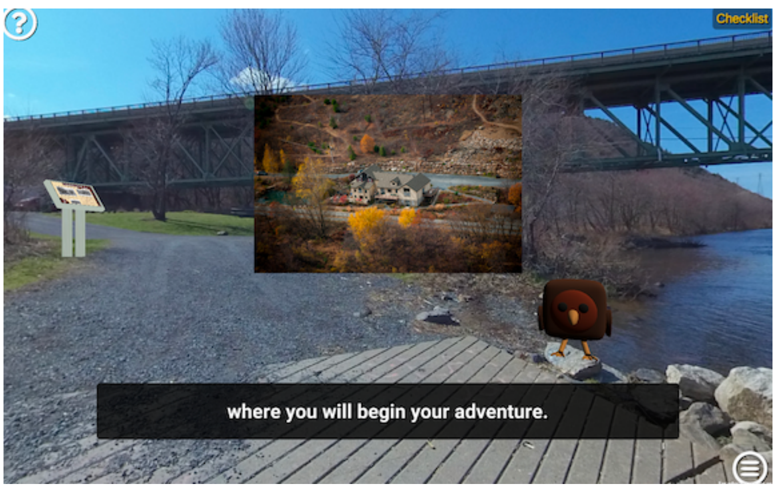

Figure 4. An image of the Osprey House, the physical building at the Lehigh Gap Nature Center is displayed during Brownie's talk. An interpretive sign can be viewed in the left part of the image.

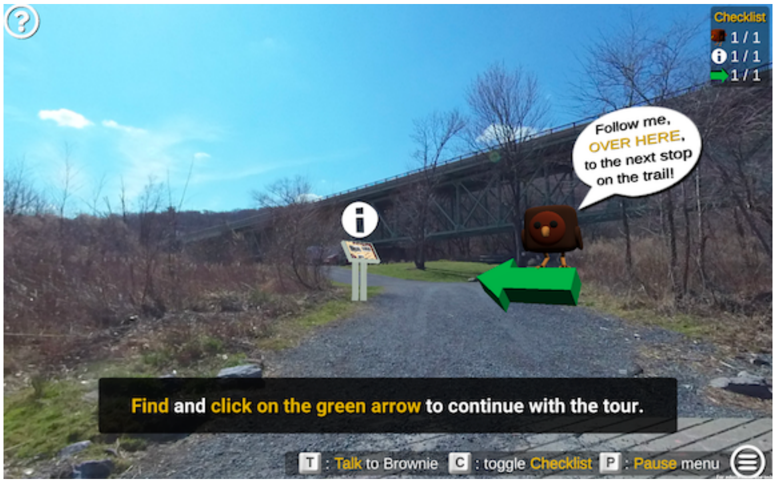

Figure 5. Image of Brownie prompting the user to move to the next photosphere.

Each photosphere focuses on a specific topic. In the second photosphere, the geology of the area is highlighted, and users are able to manipulate virtual pieces of anthracite, quartzite, sphalerite, and coal - rocks that are relevant the Lehigh Gap story (Figure 6). Users also learn about the importance of zinc for making products such as batteries. The third and fourth photospheres focus on the historical canal and railway transportation routes for bringing coal and zinc through the Lehigh Gap and also for transporting coal to areas further south in the watershed for other manufacturing processes (Figure 7). Figure 8 shows an interpretive sign. Users can click on a magnifier icon to enlarge text or images within the sign. The fifth and sixth photospheres focus on the New Jersey Zinc Company and the establishment of the town of Palmerton, PA. Users learn about the zinc smelting process to produce zinc ore and other zinc-based products (Figure 9). Next, learners view the acid rain animation to learn how the smelting process from the plant denuded the mountain (Figure 10). The final photosphere focuses on the establishment of the area as an EPA Superfund site, the testing of mixtures of warm-season grasses to restore the ecological health of the mountain, and the success of establishing diverse habitats that can be observed today (Figures 11 and 12).

Figure 6. Brownie prompting the user to examine the rocks.

Figure 7. Image of Brownie talking about the development of a railway bridge at the Lehigh Gap.

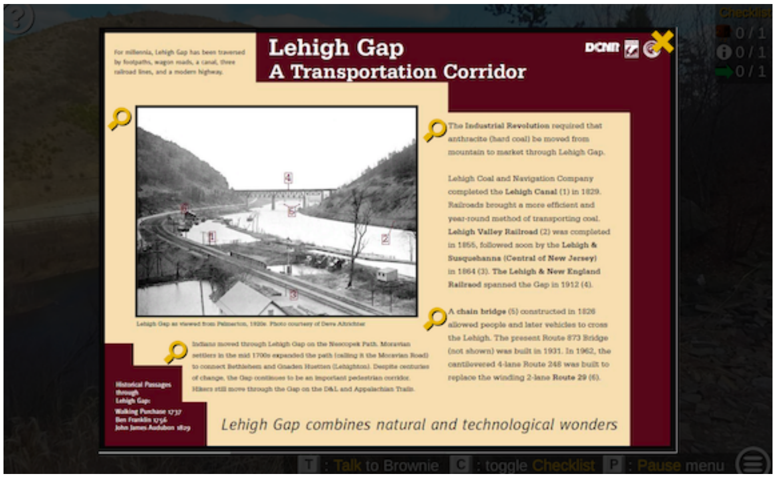

Figure 8. An example of an interpretive sign. Users can click on the magnifier icons to enlarge text and images.

Figure 9. Brownie discussing the zinc smelting process at the New Jersey Zinc Company west plant.

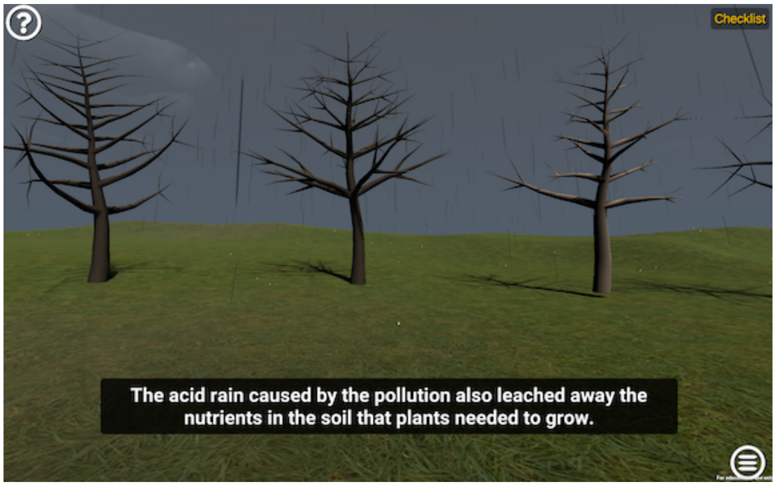

Figure 10. Image from the acid rain animation.

Figure 11. Image displaying denuded mountain inset from Brownie's narration.

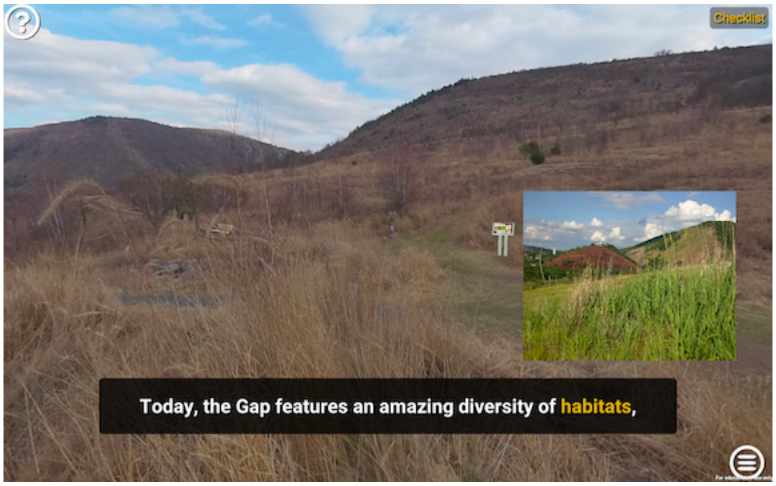

Figure 12. Current image of the Lehigh Gap with Brownie's narration highlighting habitat diversity.

Course Implementation

The dVFT was implemented in a graduate level environmental education course during spring 2021. Prior to the Saturday field trip day, students were assigned some background readings on how the Lehigh Gap became a Superfund site and about the revegetation process. In addition, the students were asked to complete the dVFT prior to class. The course included one middle school science teacher and three preservice science teachers, one of whom had spent a previous spring interning at the Lehigh Gap Nature Center. As is typical on the Saturday field trip, we began the day with a presentation by the Lehigh Gap Nature Center staff. In the spring 2021 semester, this occurred via video-conference due to the COVID-19 pandemic. We began the session with student introductions and asked the students to tell us their thoughts about the dVFT. All students stated that they found the dVFT engaging. They each noted that the imagery in the photospheres made them feel like they were actually there. Some commented that they enjoyed the background audio including natural sounds and that this helped contribute to their feeling of presence. All students commented that they enjoyed the interactive features in the photospheres. Many noted that this helped to focus their attention on learning the environmental content and understanding how the Lehigh Gap had changed over time. They enjoyed being able to take their time to explore each photosphere and read the interpretive signs. They liked avatar Brownie's narration and the historical perspective that she offered from her point of view. The students noted that the acid rain animation did a nice job conveying how the mountaintop became barren. All preservice and inservice science teachers noted that they could envision themselves using the dVFT with middle or high school students. They commented on the place-based nature of the experience and how this would enhance secondary school students' understanding of the watershed. The students also commented on the interdisciplinary nature of the dVFT, noting that the dVFT could also be used in social studies classes.

The four students came to the Lehigh Gap in the afternoon for the optional field trip with the course instructor and the Lehigh Gap Nature Center Director of Science and Education. During the hike all students commented that viewing the dVFT enhanced their actual physical field trip experience at the Lehigh Gap. They commented that it helped prime them for the field trip and assisted them with connecting with the actual physical location. They discussed how the dVFT made them feel immersed in the virtual learning experience and that their sense of place for the Lehigh Gap was initially developed through that experience. Their sense of place was then augmented by being at the actual physical location. This was an unexpected surprise for us to hear.

Conclusion and Implications for Science Teacher Educators

We view the use of the dVFT in the environmental education course as a success to promote an engaging and meaningful place-based learning experience for the students. Place-based based pedagogy involves authentic experiences in that place or in an environment that replicates the place, such as a VR environment. The students experienced both immersion and presence using the dVFT. The dVFT served two main purposes in the course. First, it provided students who were unable to attend the optional field trip with a meaningful experience to learn about an important environmental issue and remediation process. Second, the dVFT served as a valuable foundational learning activity for students to familiarize themselves with the actual field site prior to going to the physical site location. Falk et al. (1978) reported that students on field trips to outdoor sites are often placed under heavy cognitive loads that limit their ability to perceive and process all of the relevant information when in a novel environment. Based on our students' reporting of their experiences, the use of the dVFT as a pre-field trip activity likely reduced the students' cognitive load for learning during the field trip site visit by promoting their environmental content understandings as they engaged with the VR environment.

The dVFT user interface includes high-fidelity and photo-realistic imagery coupled with navigational agency for the user to freely explore the virtual environment at their own pace. This dVFT design likely assisted students with learning the environmental content. This idea is related to the findings of a previous study that reported that elementary age students working in a high-fidelity VR game simulation were well prepared to learn when later placed in the actual real-world environment upon which the game was based (Harrington, 2012).

Field trips to environmental sites can serve as powerful learning experiences for preservice and inservice science teachers. These experiences can also take place in a virtual environment. Anyone with access to a camera that takes 360° images can use freely available virtual tour creators such as Roundme (https://roundme.com/) and Paneek (https://www.paneek.net) without having to take the time to learn how to use a more robust game engine platform like Unity. Using these virtual tour creators, one can use high-fidelity imagery to craft a narrative about a specific environmental site in one's own local watershed or other locations. Furthermore, one can readily embed text, images, video, and audio into a dynamic interactive image.

The Lehigh Gap has a rich industrial history that helped our inservice and preservice teachers understand that past industrial processes that occurred on an important waterway and had devasting effects to the natural environment during a time period when there were little to no environmental regulations in place in the United States. Many institutions are located in or near watersheds that have past and current industrial processes that have resulted in environmental issues. As noted earlier, understanding and addressing environmental issues is important for promoting environmental literacy and preparing science teachers. Thus, our dVFT should have broad appeal to science teacher educators living in other geographical locations.

Many areas have non-formal environmental education or STEM-related centers that look to partner with higher education faculty to help meet their education mission to promote environmental literacy to the public. These centers are an invaluable resource that can provide science teachers educators with environmental content expertise, rich visual imagery, and other resources which can be used to enhance the development of a dVFT. The design partnership between faculty at our institution and the Lehigh Gap Nature Center created a dVFT that resulted in a superior learning experience that would likely had either partner developed the dVFT on their own.

Acknowledgement. We thank Sarah Kiel, Tyler Hogue, Austin Lordi, Brad DeMassa, Challen Adu, Kanaruj Chanthongdee, Yolanda Liu, Max Louissaint, Anthony Blakely and Brantley Balsamo for their development work with us on the dVFT.

References

Adedokun, O. A., Hetzel, K., Carleton Parker, L., Loizzo, J., Burgess, W. D., & Robinson, J. P. (2012). Using Virtual Field Trips to Connect Students with University Scientists: Core Elements and Evaluation of zipTrips™. *Journal of Science Education and Technology, 21*(5), 607-618.

Alon, N. L., & Tal, T.. (2015) Student self-reported learning outcomes of field trips: The pedagogical impact. *International Journal of Science Education, 37*(8), 1279-1298.

Association for Science Teacher Education. (n.d.). ASTE position statement on environmental and sustainability education. https://theaste.org/aste-position-statement-on-environmental-and-sustainability-education/

Bleiwas, D. I., & DiFrancesco, C. (2010). *Historical zinc smelting in New Jersey, Pennsylvania, Virginia, West Virginia, and Washington, D.C., with estimates of atmospheric zinc emissions and other materials*. (U.S. Geological Survey Open File Report 2010-1131). U.S. Department of the Interior. https://pubs.usgs.gov/of/2010/1131/pdf/OF10-1131.pdf

Bodzin, A. (2008). Integrating instructional technologies in a local watershed investigation with urban elementary learners. *The Journal of Environmental Education, 39*(2), 47-57.

Bodzin, A. (2010). Integrating Web-based activities and field-based experiences to investigate environmental issues. In Bodzin, Klein, & Weaver (Eds.) *The Inclusion of Environmental Education in Science Teacher Education* (pp. 323-336). Dordrecht, Netherlands: Springer.

Dale, R. G., Powell, R. B., Stern, M. J., & Garst, B. A. (2020) Influence of the natural setting on environmental education outcomes, *Environmental Education Research, 26*(5), 613-631, DOI: 10.1080/13504622.2020.1738346

Dolphin, G., Dutchak, A., Karchewski, B. & Cooper, J. (2019). Virtual field experiences in introductory geology: Addressing a capacity problem, but finding a pedagogical one. *Journal of Geoscience Education, 67*(2), 114-130. https://doi.org/10.1080/10899995.2018.1547034

Clary, R. M., & Wandersee, J. H. (2010). Virtual field exercises in the online classroom: Practicing science teachers' perceptions of effectiveness, best practices, and implementation. *Journal of College Science Teaching, 39*(4), 50–58.

Falk, J.H., Martin, W. W., Balling, J.D. (1978). The novel field trip phenomena: Adjustment to novel settings interferes with task learning. *Journal of Research in Science Teaching, 15*(2), 127-134.

Fisman, L. (2005). The effects of local learning on environmental awareness in children: An empirical investigation. *The Journal of Environmental Education, 36*(3), 39-50.

Fox, M. C. (2019). *Geography, geology, and genius: How coal and canals ignited the American industrial revolution*. Easton, PA: Canal History and Technology Press.

Freina, L. & Ott, M. (2015). *A literature review on immersive virtual reality in education: state of the art and perspectives*. Paper presented at the conference proceedings of eLearning and software for education.

Harrington**,** M. C. R. (2012). The Virtual Trillium Trail and the empirical effects of freedom and fidelity on discovery-based learning. *Virtual Reality, 16*(2), 105-120. https://doi.org/10.1007/s10055-011-0189-7

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., & Walton, A. (2008). Measuring and defining the experience of immersion in games. *International journal of human-computer studies, 66*(9), 641-661.

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies, 23*(4), 1515-1529.

Jessor, R. (1996). Ethnographic methods in contemporary perspective. In R. Jessor, A. Colby, and R.A. Shweder (Eds.), *Ethnography and human development*. Chicago: University of Chicago Press.

Klippel, A., Zhao, J., Oprean, D., Wallgrün, J. O., Stubbs, C., La Femina, P., & L., J. K. (2019). The value of being there: toward a science of immersive virtual field trips. *Virtual Reality*. https://doi.org/10.1007/s10055-019-00418-5

Langran, E. & DeWitt, J. (2020). *Navigating placed-based learning*. Cham, Switzerland : Springer.

Lave, J., and Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Litherland, K., & Stott, T. A. (2012). Virtual field sites: Losses and gains in authenticity with semantic technologies. *Technology, Pedagogy and Education, 21*(2), 213–230. https://doi.org/10.1080/1475939X.2012.697773

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education, 70*, 29-40. https://doi.org/10.1016/j.compedu.2013.07.033

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press.

North American Association for Environmental Education (2017). Guidelines for excellence. Professional development of environmental educators. NAAEE: Rock Springs, GA.

Orion, N., & Hofstein, A. (1991). The measurement of students' attitudes towards scientific field trips. *Science Education, 75*, 513-523.

Orion, N., & Hofstein, A. (1994). Factors that influence learning during a scientific field trip in a natural environment. *Journal of Research in Science Teaching, 31*, 1097-1119.

Rogoff, B. (2003). *The cultural nature of human development*. New York: Oxford University Press.

Sanchez-Vives, M.V., Slater, M. (2005). From presence to consciousness through virtual reality. *Nature Reviews Neuroscience, 6*, 332–339.

Sarkar, S., & Frazier, R. (2010). Place-based inquiry: Advancing environmental education in science teacher preparation. In Bodzin, Klein, & Weaver (Eds.) *The Inclusion of Environmental Education in Science Teacher Education* (pp. 323-336). Dordrecht, Netherlands: Springer.

Semken, S., Ward, E. G., Moosavi, S. & Chinn, P. W. U. (2017). Place-based education in geoscience: Theory, research, practice, and assessment. *Journal of Geoscience Education, 65*(4), 542-562, DOI: 10.5408/17-276.1

Shweder, R.A. (1996). True ethnography: The lore, the law, and the lure. In R. Jessor, A. Colby, and R.A. Shweder (Eds.), *Ethnography and human development*. Chicago: University of Chicago Press.

Shepardson, D. P., Wee, B., Priddy, M., Schellenberger, L., & Harbor, J. (2007). What is a watershed? Implications of student conceptions for environmental science education and the national science education standards. *Science Education*, *91*(4), 554-578.

Sobel, D. (2004). *Place-based education: Connecting classrooms and communities*. Great Barrington, MA: The Orion Society.

Slater, M. (2003). A note on presence terminology. *Presence Connect, 3*(3), 1–5.

Thomas, T. G. (2020). Place-based inquiry in a university course abroad: lessons about education for sustainability in the urban outdoors. *International Journal of Sustainability in Higher Education*, 21(5), 895-910. https://doi.org/10.1108/IJSHE-07-2019-0220