CHAPTER

5

Virtual reality as a promising tool to promote climate change awareness

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The rapid expansion of the human population and the increasing exploitation of resources are disrupting the functioning of the Earth's systems. Currently, one of the primary disruptions of human activity is the consistently increasing emission of greenhouse gases, such as carbon dioxide and methane, leading to a greater greenhouse effect. The trapping of more heat in the atmosphere subsequently increases the average temperature on Earth, modifying the global climate—an issue commonly known as climate change. Recently, the Intergovernmental Panel on Climate Change (IPCC, 2018) warned that we need to make rapid, far-reaching, and unprecedented changes in all aspects of our societies in order to limit global warming to 1.5°C. The extent and success of mitigation and adaptation strategies will greatly vary across regions and will be strongly influenced by the level of governance, wealth, technology, and infrastructure. In turn, this will result in major discrepancies in how human health will be impacted by the health of our planet (Myers, 2017). Moreover, often, the populations that benefit from human climate change–contributing activities are not the ones suffering from their consequences. These inequalities make it essential for human beings to realize that we are all connected. Individuals need to understand and be able to address the environmental issues. That is, people need to be environmentally literate.

Building on prior work, the environmental literacy framework developed by Hollweg et al. (2011, p. 2–3) defined "an environmentally literate person as someone who, both individually and together with others, makes

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informed decisions concerning the environment; is willing to act on these decisions to improve the well-being of other individuals, societies, and the global environment; and participates in civic life."

Unfortunately, promoting environmental literacy is a challenging endeavor. First, many environmental issues are partly or completely invisible, for example, greenhouse gases. It is important for citizens to understand how their everyday life actions are responsible for releasing CO_2 and other greenhouse gases. Because these gases are invisible to the naked eye, it is difficult for people to grasp not only the extent of their emission but also the behaviors that are the most damaging for the environment.

Second, much environmental degradation often takes place far away (temporally and spatially) from their cause. The negative consequences of our actions might only be felt by the future generations, or by our contemporaries who live far away from us or belong to another demographic of the local population. This temporal, spatial, and social distance leads to a psychological disconnect, which in turn has led to a lack of personal concern due to the underestimation of the severity of environmental issues (Trope & Liberman, 2010; Weber, 2006).

A third challenge relates to the importance of experiencing nature firsthand in order to develop some connectedness with nature, which is central to proenvironmental behaviors (Bruni, Chance, Schultz, & Nolan, 2012). Experiencing nature is not always an easy task, as some environments that are essential to learn about are often too far away, too expensive to visit, or pose some safety issues.

A final challenge is related to the difficulty of experimenting with the environment. Running experiments to learn about certain environmental issues can require long periods of time to see any effects as well as complex techniques or components that might be dangerous for untrained researchers.

Over the last decades, digital technologies have provided increasing access to information, knowledge, and experiences to individuals around the world. An important characteristic of digital technology is its multimodality—the ability to include texts, images, animations, sound and even haptic feedback to create rich and engaging experiences through a steadily growing supply of interactive applications. Making the invisible visible is a key opportunity offered by digital technologies. By enabling users to visualize something that would otherwise be invisible to them, such as their carbon footprint, digital technologies make it possible to engage with the environmental issues in more specific and engaging ways (Ahn et al., 2016; Fauville, 2017; Fauville, Lantz-Andersson, Mäkitalo, Dupont, & Säljö, 2016). Technologies also allow people to visit places that are inaccessible, far away, do not exist anymore, or even never existed (Jacobson, Militello, & Baveye, 2009; Tarng, Change, Ou, Chang, & Liou, 2008; Tarng, Ou, Tsai, Lin, & Hsu, 2010). Finally, technology can support virtual scientific experiments that otherwise would be out of reach in the real world (Petersson, Lantz-Andersson, & Säljö, 2013).

Immersive virtual reality for environmental literacy

Through the use of a head-mounted display (HMD), hand controllers, stereoscopic sound, and haptic feedback, immersive virtual reality (IVR) provides a vivid first-person experience in a three-dimensional virtual environment augmented with multisensory feedback.

IVR allows users to perceive with multiple senses as if they were actually in the real world. This very unique sense of *being there* is called psychological presence (Heeter, 1992; Slater & Wilbur, 1997). The subjective feeling of presence is what makes the IVR user of an earthquake experience, who is physically in a large empty room, drop to their knees and dive under a virtual table that exists only in the virtual world. The earthquake does not present any physical risk to the user but manages to trigger this reaction of seeking protection (Bailenson, 2018).

As defined by Witmer and Singer (1998, p. 227), "Immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences." Virtual experiences have become more immersive as technological development increases the sensory information provided, allowing users to feel more in touch with the virtual experiences. For example, highly immersive IVR tracks the user's body movements and renders them accurately for the user to feel like their arms and legs are naturally moving in the virtual world, thus creating a sense of presence (Wirth et al., 2007). Another important aspect of IVR is its impact on social behavior triggered by taking the perspective of another person, which is known as virtual reality perspective taking. Becoming someone of a different gender, ethnicity, generation, or species is easy in IVR and has been shown to promote positive prosocial behavior such as inducing helping behavior (Ahn, Le, & Bailenson, 2013), decreasing racial bias (Hasler, Spanlang, & Slater, 2017), and decreasing ageist bias (Oh, Bailenson, Weisz, & Zaki, 2016).

A systematic literature review about the use of various immersive virtual environments (such as augmented, virtual, and mixed reality) identified an increasing number of studies in the last decade focused on the particular environmental issue of climate change (Queiroz, Kamarainen, Preston, & Leme, 2018). In this review, studies were categorized according the three components of engagement necessary to elicit change in the public perspective of climate change, proposed by Ockwell, Whitmarsh, and O'Neill (2009): understanding, emotion, and action. The authors highlighted that although a significant number of studies reported positive outcomes of using IVEs for climate change understanding, few studies investigated more than one component of engagement. They indicated the need for future studies to investigate how virtual experiences could tap into all three dimensions to have a greater understanding of the potential of virtual environmental experiences and climate change engagement. Climate change is just one of many subjects embedded in environmental literacy, and research on the impact of immersive virtual environments for environmental literacy is still in its infancy. Nevertheless, existing studies demonstrate an encouraging sign that immersive virtual environments could be a game changer in promoting environmental literacy and present an avenue for future research. In this chapter, we will describe empirical studies investigating the use of IVR in subjects within environmental literacy dimensions and discuss the implications for future IVR applications and research.

To collect the studies reviewed in this chapter, we searched the following online databases: ERIC, PubMed, IEEE, Scopus, Springer, ACM, and Web of Science. After an exploratory search, the search terms were defined and included a combination of the following: "virtual reality," "immersive technologies," "immersive virtual environments," "virtual environment technologies," "head-mounted display," "environmental education," "climate change," "sustainability," "ecosystem," and "proenvironmental behavior." Only peer-reviewed, empirical studies using head tracking via HMD setup were included in this review. We identified 13 papers (Table 5.1). Then, the papers were categorized based on the four dimensions of environmental literacy. Being environmentally literate is not a binary condition, but instead, it is comprised of a wide range of aspects that are intertwined and therefore influence each other. All of these various aspects can be categorized in the following four multifaceted dimensions of environmental literacy (Cook & Berrenberg, 1981; Hungerford & Volk, 1990; Stern, 2000):

- *Knowledge*: Being environmentally literate requires some degree of knowledge of Earth's science along with physical and ecological systems. Moreover, it is essential to understand the social, political, economic, and cultural influences on the environmental issues and the fact that there are multiple solutions to these issues.
- *Dispositions*: This dimension includes sensitivity, attitude toward the environment, assumption of personal responsibility, self-efficacy, motivation, and intention to act.
- *Competencies*: In this, dimension are skills and abilities such as identifying, analyzing, evaluating, and making personal judgments

TABLE 5.1 Overview of the studies presented in this chapter.

References	Topics addressed	Presented in section	Factors that impacted environmental literacy	Factors that did not impact environmental literacy
Moreno and Mayer (2002)	Botany	1	Speech narration (narration vs. text)	Level of immersion (HMD vs. desktop)
Moreno and Mayer (2004)	Botany	1	Personalization	Level of immersion (HMD vs. desktop)
Ahn, Bailenson, and Park (2014)	Paper consumption	2 and 3	Level of immersion (IVR, video, and print) (D and B)	Level of immersion (HMD vs. print) (D)
Bailey et al. (2015)	Hot water use	3	Level of vividness	Level of personalization
Ahn et al. (2016)	Cattle treatment and ocean acidification	2	Exp 1: Level of immersion (becoming a cow in IVR vs. watching someone else embodying a cow on video) Exp 2: Level of immersion right after the experience	Exp 2: Level of immersion a week after the experience Exp 3: Level of immersion (HMD without haptic feedback vs. video)
Fonseca and Kraus (2016)	Meat consumption	3	Level of emotion	N/A
Knote, Edenhofer, and von Mammen (2016)	Invasive species	4	N/A	N/A
Nim et al. (2016)	Coral reef	4	N/A	N/A
Calvi et al. (2017)	Diving	4	N/A	N/A

Continued

TABLE 5.1 Overview of the studies presented in this chapter.—cont'd

References	Topics addressed	Presented in section	Factors that impacted environmental literacy	Factors that did not impact environmental literacy
Mc Millan et al. (2017)	Virtual ocean exploration	4	N/A	N/A
Soliman, Peetz, and Davydenko (2017)	Nature and built environment	2 and 3	Environment of the experience (nature vs. build) (D)	Level of immersion (D)
Hsu, Tseng, and Kang (2018)	Water conservation	2	Focus of negative impact (resources vs. environment)	N/A
Markowitz, Laha, Perone, Pea, and Bailenson (2018)	Ocean acidification	1 and 2	Visual exploration and engagement (K)	Nature of the avatar (K) Nature of the avatar (D) Level of motion (K) Level of motion (D)

Focus of the four sections: Section 1: proenvironmental knowledge, Section 2: proenvironmental disposition, Section 3: proenvironmental behaviors, and Section 4: descriptive papers. In the two last columns of the table, the factors that did or did not impact the studied dimension of environmental literacy are presented. The letters (B), (D), and (K) indicate that environmental dimension was studied: (B); environmental behavior, (D); environmental disposition, and (K); environmental knowledge.

concerning environmental issues, along with asking relevant questions, argumentation, and creation and evaluation of strategies to resolve these environmental issues.
- *Environmentally responsible behavior:* This dimension includes behaviors people engage in both individually or in a group toward solving current environmental issues and preventing new ones.

The 13 papers included in this review are summarized in four sections. The first three sections present the findings from empirical studies investigating, respectively, three out of the four environmental literacy dimensions: knowledge, dispositions, and behavior. We did not create a section for proenvironmental competencies because we could not find any publications addressing this dimension. The last section summarizes descriptive publications that do not include empirical data.

IVR for promoting the knowledge dimension of environmental literacy

In this section, we describe studies that investigated how different aspects of IVR could promote environmental knowledge, and we discuss how their findings could support future IVR application and research for promoting environmental literacy. The knowledge dimension of environmental literacy encompasses some knowledge of the Earth's physical and ecological systems. It is also crucial to have knowledge concerning the social, political, economic, and cultural influences on the environment. Moreover, it is essential to understand the roles that all these elements play in the health of the environment and how they are interconnected.

Moreno and Mayer (2002) explored the impact on learning of different media and instructional methods in virtual botany learning activity. The goal of this activity was to design a plant that would be able to flourish on an alien planet with specific environmental conditions. The authors conducted two experiments. In the first one, 89 college students were randomly assigned to 1 of the 6 different conditions (modality of verbal information: narration or text combined with level of immersion: desktop, HMD and sitting, or HDM and walking). At the end of the activity, the participants were prompted to answer retention and task-based tests in order to assess learning. The results demonstrated that the students in the speech narration condition outperformed the students in the text condition but that the level of immersion did not have an impact on the knowledge gain.

In their second experiment, 75 college students used the same virtual learning activity and were randomly assigned to six different conditions (modality of verbal information: text, narration or both combined with the level of immersion: desktop or HMD). The findings of this second experiment aligned with the first one, as the students in the text conditions performed significantly worse than the students in the other groups. Moreover, the knowledge gain was not correlated with the level of immersion.

In 2004, Moreno and Mayer used the same virtual botany learning activity to investigate the impact of personalized message on learning. In this activity, a pedagogic agent would offer information to help the students design a plant adapted to the environmental conditions. In the personalized condition, the agent used the first and second person ("I" and "You") as if the student and the agent were sharing the experience. The language used in the nonpersonalized condition was more formal as students received explanations in the third person. The activity was either experienced on a desktop or on an HMD. At the end of the activity, the 48 participants were prompted to answer knowledge tests similar to those in the previous study (Moreno & Mayer, 2002). The students in the personalized conditions significantly outperformed the students in the nonpersonalized conditions. This effect was observed across the two levels of immersion, revealing that the level of immersion of the media did not influence the learning gain.

More recently, Markowitz et al. (2018) explored the efficacy of an IVR for teaching about the consequences of climate change. The IVR activity was first implemented in school as part of a teaching unit running over several weeks. The students embodied a coral avatar and experienced the ill effect of ocean acidification on other species and on their own avatar. The students' knowledge about the topic increased after participating in the IVR activity.

A similar experiment was run, but this time, half of the participants saw themselves as a coral, while the other half embodied a scuba diver. Both groups presented a significant knowledge gain between pre- and posttest, but there was no difference between the two conditions. This indicates that, in this case, the nature of the avatar did not influence the knowledge gain.

A third experiment was focused on the movement in IVR. In this IVR activity, 43 participating college students were randomly assigned to two motion conditions (swimming with remote control or with their physical body). While the motion condition did not influence the knowledge gain, it showed a posthoc correlation between the knowledge gain, the total number of snails found, and the distance traveled underwater. This suggested that visual and physical exploration while in IVR led to a greater knowledge gain.

Although several studies have investigated the effects of desktop-based VR on learning (Dede, 2009; Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014), research on IVR is in its infancy, and how it affects learning is still unclear (Makransky, Terkildsen, & Mayer, 2017; Suh & Prophet, 2018; Southgate et al., 2019). Even less is known with regard to environmental knowledge.

Findings from the reviewed studies suggest that the effects of design of the virtual environment in learning outcomes may be more relevant than the level of immersion itself. Research comparing different IVR designs is needed to understand how immersive virtual environments can effectively promote the knowledge dimension of environmental literacy.

IVR for promoting the dispositions dimension of environmental literacy

In this section, we present and discuss the studies investigating IVR effects on environmental disposition. The environmental dispositions' dimension of Environmental Literacy encompasses a wide range of psychological attitudes. These dispositions can be seen as environmental sensitivity, attitude or concern, or as assumption of personal responsibility, locus of control/self-efficacy, or intention to act. Five studies investigated environmental dispositions and how they could be influenced by IVR (Ahn et al., 2014, 2016; Hsu et al., 2018; Markowitz et al., 2018; Soliman et al., 2017)

Ahn et al. (2014) investigated the impact of an embodied experience in IVR on environmental behavior and locus of control related to paper consumption. In a first experiment, 47 college students were first informed about paper consumption and its impact on deforestation before being randomly assigned to one of two experimental conditions. Half of the participants put on the HMD and virtually stood in a forest in front of a large tree while holding a chainsaw. They were asked to pay attention to the forest, such as the sound of the birds, before feeling and hearing the chainsaw start-up. They were then prompted to begin moving a haptic joystick to cut the tree down. After 2 minutes of sawing, the tree would fall down, and the forest became suddenly quiet. The rest of the participants simply read a detailed description of the tree-cutting activity and were prompted to create a vivid picture in their minds of this activity. The participants in both conditions demonstrated a significant increase in their belief that their individual actions could be meaningful for the environment, but there was no difference between the two conditions.

The second experiment was similar to the first one, but this time data were collected right after the activity and 1 week later by email. Also there were three conditions for the tree-cutting experience; IVR, video, and print. The participants in the IVR condition showed a significantly higher environmental locus of control compared with the video conditions and marginally higher to the text condition. The findings also revealed that the environmental behavior intention of the participants in the IVR conditions was significantly higher than the participants in the print conditions and marginally higher than the participants in the video condition.

Ahn et al. (2016) conducted a study to investigate how embodying animals in IVR affected inclusion of nature in self (INS; experiencing the connection between nature and self) and involvement with nature. Three experiments were designed to compare the spatial presence, body transfer (the illusion of becoming a virtual body), and INS among individuals embodying a cow in the virtual environment versus those watching a video of the experience. Results suggested that the sensory richness provided by IVRs contributed to greater spatial presence and a more salient experience than watching the same experience in video. Also, only body transfer seemed to consistently drive increased INS, highlighting the importance of IVR in users' feeling of ownership over the embodied animal. In addition, their results suggested that having visual control of the experience seemed sufficient for users to feel this ownership.

Soliman et al. (2017) investigated the impact in nature connectedness, INS, and proenvironmental behavior of watching nature-based video (nature condition) compared to video of a human-built environment (built condition) either on desktop or IVR. After watching the videos, the 230 participants reported their attitude toward nature in two different measures—INS and the connectedness to nature scale (CNS). The participants in the nature conditions reported significantly greater INS and CNS compared with the participants watching the built videos, while the effect of the medium was not significant to nature connectedness, which replicated Ahn et al. findings (2016).

The study of Markowitz et al. (2018; described in the previous section) also paid attention to the environmental disposition. In their first experiment (where school students embodied a coral), the participants did not show an increase in environmental attitude (measured with the NEP scale) after the IVR activity.

In their second experiment, where students embodied either a coral or a scuba diver, there was a significant increase in proenvironmental behavior between pre- and posttest, but no difference between conditions. The CNS also revealed a significant positive attitude change from pre- to posttest, but, again, no difference was found between the two conditions.

The third experiment in this set of studies was conducted at the Tribeca Film Festival. The amount of movement of the 448 participants was recorded. The authors did not find a correlation between the attitude and the amount of movement.

The fourth experiment explored further how movement could correlate to disposition toward the environment (measured with the NEP and CNS scales) and did not reveal any significant effect.

Hsu et al. (2018) investigated the effects of exaggerated feedback to trigger affective response in IVR experience about water conservation. The authors focused on the effect of exaggerated feedback intensifying the negative consequences of water consumption and/or environmental damage in order to emphasize affective responses. 165 student participants played an IVR game simulating water consumption effects. Participants were assigned to one of the four exaggerated feedback conditions: negative impact on the environment (present or absent) and negative impact on resources (present or absent). Participants in the "negative impact on resources" condition demonstrated higher short-term behavior intention to reduce water use than participants in the "negative impact on the environment" condition. Regarding long-term effects of exaggerated feedback, participants in the "negative impact on the environment" condition showed a greater improvement in individual attitude and behavior intention than participants in the other conditions. These results indicated that providing exaggerated feedback of water usage on the environment (i.e., degradation of the environment) elicited the highest levels of affective response and proenvironmental disposition.

IVR for promoting the behavior dimension of environmental literacy

In this section, we discuss the studies focusing on how IVR affects behaviors toward the environment. Environmental literacy includes the ability to engage in service and action to improve the environment. These behaviors can take different forms such as direct conservation and restoration of natural environments, consumer behaviors, and public participation in interpersonal deliberations and debates. Four studies investigated how IVR activities could promote the behavioral dimension of environmental literacy (Ahn et al., 2014; Bailey et al., 2015; Fonseca & Kraus, 2016; Soliman et al., 2017).

Ahn et al. study (2014; described in the previous section) revealed that after experiencing how to cut a tree in the IVR condition, participants used significantly fewer napkins to dry spilled water than participants who read a passage about cutting a tree.

Bailey et al. (2015) investigated the impact of vividness and personalization of feedback on reducing energy consumption related to hot water use. Four versions of an IVR activity where the user took a shower were created, combining two levels of vividness and personal message (vivid, personal; nonvivid, personal; vivid, nonpersonal; nonvivid, nonpersonal). Before and after getting into IVR, the participants were asked to wash their hands for sanitary purposes. The findings revealed that after treatment, the participants in the vivid conditions used significantly colder water than the participants in the nonvivid conditions. As the vivid condition used images of coal, while the nonvivid condition used text, the authors suggested that the vivid condition may require a lower cognitive effort than the nonvivid condition based on text. They argued that the lower cognitive effort might allow participants to better process the impact of hot water on energy consumption, which can contribute to better message processing and ultimately stimulate behavior change.

Fonseca and Kraus (2016) investigated the impact of the degree of immersion and the narrative content on environmental behavior. In this case, they focused on meat consumption. The 64 participants in the two first conditions watched an emotional 360 video about the effects of meat consumption and its relation to climate change either in IVR or on a tablet. The participants in the third condition watched a nonemotional video unrelated to meat consumption in IVR. After watching the video, the participants were offered a buffet of pizza (with or without meat). The participants in the IVR conditions marginally chose more vegetarian pizza than the participants in the nonimmersive condition. In the nonemotional condition, not a single participant chose the vegetarian option. These findings suggested that the level of immersion increased the emotional impact on the viewers and increased proenvironmental attitude.

As previously described, Soliman et al. (2017) studied the impact of watching videos on a desktop or in IVR of natural or human-built environments on proenvironmental behavior. After watching the videos, the participants' proenvironmental behaviors were assessed. They were asked if they wanted a printed or digital copy of the debriefing to subscribe to a monthly newsletter with information about practical tips on sustainability or to get a copy of the sustainability strategic plan of the campus. No significant effect of the type of media, content (nature or urban environment), or interaction was identified between the conditions.

IVR for environmental literacy: descriptive publications

Four publications (Knote et al., 2016; Calvi et al., 2017; Nim et al., 2016; McMillan, Flood, & Glaeser, 2017) described IVR activities that could be used to promote environmental literacy, but without accounting for any empirical data that could support the efficacy of these activities in promoting environmental literacy. While these studies do not provide empirical data concerning the impact of IVR on environmental literacy, they nonetheless provide important information of current IVR activities focusing on the natural environment that could potentially promote environmental literacy. Empirical research is a very long process moving at a slower pace than the technology itself. These kinds of descriptive publications present the advantage of a quick turnover and allow researchers to be kept updated about the latest IVR activities in a timely manner.

Knote et al. (2016) described an IVR activity where the user explored the competition between two species of ants—native and an invasive one. The goal was to help the native species survive the invasion by modifying their environment such as placing a brick on the ants' path, using a water hose, or spraying pheromone or hydrocarbons.

Nim et al. work (2016) focused on the health of the Great Barrier Reef and the indirect impact that the users' water and carbon footprints have on this ecosystem. In this activity, the users started off by answering questions to calculate their footprint. Then, in pairs, participants observed the coral reef bleaching along with an outbreak of a coral predator. Information concerning the indirect impacts of human activities on this ecosystem were also provided to the users. After this activity in dyads, the users were individually immersed through an HMD (Google Cardboard or Oculus DK2) in an environment where the ecosystem's health was correlated with their own water and carbon footprints calculated earlier in the activity (high footprint lead to more sea stars and coral bleaching). During this individual activity, the participants could talk to each other in order to describe and discuss their own ecosystem.

McMillan et al. (2017) described a scuba diving IVR activity that enables users to virtually explore the ocean with Dr. Sylvia Earle—famous ocean explorer—and experience the beauty of the ocean. First intended as an educational tool to fit in the Common Core Curriculum, this activity, available both on desktop and IVR, became a diving simulator.

In 2017, Calvi et al. created an IVR activity to teach about underwater sustainability. In this activity, users experienced the underwater world by virtually driving an underwater vehicle. This activity was implemented at a Science Festival. One hundred participants from primary school age to adults experienced this IVR activity and answered questionnaires. Children up to 10 years old played for almost half of the time compared with other participants and reported the experience as extremely real in comparison with adults. Children also considered the visual effects and control devices to be more distracting than the other groups. These results identified the need for studies investigating if/how feeling high presence in IVR could enhance empathy and increase the engagement with environmental issues, as well as studies targeting different age groups.

Moving forward

This chapter accounts for the current state of research in the field of IVR for environmental literacy as a way to promote climate change awareness. Approximately, a dozen publications over a period of 17 years are presented in this chapter, which illustrates how young this field is and how much more needs to be researched in order to understand how IVR can impact individuals' environmental literacy.

IVR has been evolving rapidly over the course of the last 5 years. Ahn and colleagues in 2014 used an HMD called NVIS SX111 that weighted 1.3 kg and was tethered through a heavy cable to a powerful computer while the interactivity took place through a bulky joystick (Fig. 5.1). The tracking system used with the NVIS SX111 was composed of eight cameras, and the entire IVR system cost about $100,000.

Today, individuals can easily purchase their own IVR systems with hand controllers and an HMD (weighting less than 500 g) for less than $400. This technological evolution has a profound impact on the role that IVR can play in society—specifically on environmental issues and on the research that can be carried out. Research in IVR used to be confined to a handful of advanced research facilities. The physical inaccessibility of the equipment also limited research participants to university students with easier access to these facilities. Now researchers can bring IVR devices to classrooms, supermarkets, or medical centers and study how a wide variety of individuals react to this novel technology. This evolution has tremendously widened the horizons of researchers who can now

FIGURE 5.1 Experimental setup used by Ahn et al. in 2014.

investigate how individuals with different backgrounds, political views, cultures, or environmental attitudes will react to the use of IVR for environmental literacy (Song & Fiore, 2017).

The fields of research and technology typically have very different timeframes. While technology is frequently replaced by a newer, cheaper, faster, and more sophisticated version within a year, empirical evidence of what a technology can do takes several years to come to fruition, from the design of the experiments to the publications of the results in peer-reviewed journals. Because both the technology and the environmental problems are evolving at a fast pace, it is essential to encourage and maintain a joint effort from the research community to understand what technology can do, in order to promote environmental literacy as soon as possible. The emergence of multidisciplinary research teams working toward understanding how IVR can address one of the most pressing societal issues would be of great benefit for our society.

As described earlier in this chapter, to be considered environmentally literate, a person needs to possess the four dimensions of environmental literacy (knowledge, dispositions, competencies, and environmentally responsible behavior) in various degrees. Moreover, enhancing one of these dimensions might help the individual move forward in the other dimensions, creating a network between all four. It is therefore essential to investigate how VR can promote each of these dimensions in order to have a holistic impact on the development of environmental literacy among the public. As studies on IVR applications are mostly recent, we found that each dimension has only been studied in relation to IVR in a very limited amount. To the best of our knowledge, one of the four dimensions has yet to be investigated. Moreover, no publication has been found, which looks at the impact of IVR on the four dimensions simultaneously. This chapter demonstrates the limited current knowledge in this field and advocates for strengthening the effort from the research community to shed light on the role that IVR could play in promoting the dimensions of environmental literacy—individually or synergistically.

Another challenge is that little is known about what features of the content of learning activities in IVR are key to making these immersive activities effective for environmental literacy. We still need to discover in which conditions IVR constitute an efficient teaching method and what kind of content can be leveraged by this technology.

Another issue resides in the timeframe of the current studies. The 13 studies presented in this chapter present a very short duration of exposure to IVR. Several researchers suggested investigating the impact of multiple exposures (of different lengths) over time (Ahn et al., 2014; Hsu et al., 2018; Song & Fiore, 2017). Another key question is how long the effects of IVR will last on the subject. Most of the studies have measured the outcome variable of interest right after the exposure to IVR. Exploring long-term effect of IVR on ES with longitudinal studies would be valuable.

Besides directly impacting an individual's environmental literacy, IVR also has the potential to help investigate individuals' behaviors in situations that are difficult to create or control in the real world. For example, Verhulst, Lombar, Normand, and Moreau (2017) addressed food waste by studying how consumers would react to misshapen fruits and vegetables by exposing and allowing them to manipulate these foods in IVR. Running this study in IVR instead of in the real world made it possible to overcome experimental challenges that would have made the experiment difficult to run otherwise. The authors argued that "By replacing real fresh products with virtual ones we could ensure the repeatability of user studies as well as easily control different aspects of freshness or appearance (e.g., misshaped products) and evaluate the consumer behavior of participants" (p. 55).

The same technique was used by Khashe, Lucas, Becerik-Gerber, and Gratch (2017) to investigate how building occupants would comply with proenvironmental behavior suggestions delivered in different ways to their computer (gender of the voice, communicators person, delivery styles). Running this study in IVR rather than in real life allowed them to focus on the variable of interest while keeping the other variables constant (e.g., weather condition that might influence compliance with a lighting-related request such as opening the blind rather than turning the light on). Besides being used directly to educate people about environmental issues and reduce the psychological distance between humans and the environment, IVR presents an important potential to mimic real life and investigate how different strategies implemented in real life could make them more environmentally literate.

Importantly, using IVR for environmental literacy should be considered as an addition to other learning activities, not a substitute. Although immersive technology has evolved significantly, its fidelity to the natural setting is still low, and a real experience in nature should be favored over its virtual equivalent. Moreover, adding IVR to the classrooms should be done cautiously, considering the strengths and weakness of IVR for education purpose (Parong & Mayer, 2018). In other words, IVR represents a new learning tool that can potentially be efficient in promoting the various dimensions of environmental literacy among the public as demonstrated by the studies presented in this chapter.

In conclusion, the emergence of IVR as an affordable and increasingly mobile technology opens interesting possibilities to promote environmental literacy. It also requires the attention of the IVR research community in order to make the best use of this novel technology to address environmental problems that threaten our own survival and the health of the planet.

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