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Current Opinion in Psychology

Review

Virtual reality and the psychology of climate change

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Abstract

Researchers and practitioners have used virtual reality (VR) as a tool to understand attitudes and behaviors around climate change for decades. As VR has become more immersive, mainstream, and commercially available, it has also become a medium for education about climate issues, a way to indirectly expose users to novel stimuli, and a tool to tell stories about antienvironmental activity. This review explicates the relationship between VR and climate change from a psychological perspective and offers recommendations to make virtual experiences engaging, available, and impactful for users. Climate change is perhaps the most urgent global issue of our lifetime with irreversible consequences. It therefore requires innovative experiential approaches to teach its effects and modify attitudes in support of proenvironmental actions.

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Current Opinion in Psychology 2021, **42**:60–65

This review comes from a themed issue on **Psychology of Climate Change**

Edited by **Mark F. Ferguson** & **Michael T. Schmitt**

For a complete overview see the Issue and the Editorial

Available online 31 March 2021

https://doi.org/10.1016/j.copsyc.2021.03.009

Keywords

Virtual reality, Climate change, Education, Novel exposure, Storytelling.

Virtual reality and the psychology of climate change

Social scientists often try to create a laboratory environment for participants to act naturally and accurately report how they feel after a stimulus or experience. A constraint in this empirical process is that participants respond to what they currently see or they are forced to recollect how a past or imagine what a future self might do via a survey question. This model has characterized social science research for over a century, but the past 20 years of virtual reality (VR) research has operated under a different set of rules [1]. In VR, people do not have to imagine themselves years into the future [2,3]; they can become older virtually and experience their future self by transferring to a new body. In VR, people do not have to approximate homelessness [4]; they can take the perspective of someone who has been evicted and simulate the experience as if it was real. VR technology has been applied to fields such as climate science education [5] and psychotherapy [6], with positive effects that compare to or, in some cases, surpass in-person treatments. It is time to no longer discuss the potential of VR but instead to focus on how to scale its use effectively and responsibly.

The current article reviews the connection between VR and one of the most important global issues, climate change. Although more than half of Americans polled by the American Psychological Association believe that climate change is the most pressing issue facing the world [7], more than half of those polled also suggest they "don't know where to start" to address the problem. How can we confront climate change issues when most people do not know how to address the crisis? Here, we review psychological evidence that supports how VR can be a tool to teach complex climate science, make people care about the issues, and indirectly expose them to natural environments that would be otherwise impossible or unsafe. Prior reviews have evaluated the relationship between VR and climate change historically [8,9], although we focus on recent research to provide a state of the field. We conclude with paths forward to further understand the psychology of climate change with VR technology.

In this review, we evaluate research that uses immersive (e.g. using a head-mounted display with head and hand tracking) and desktop VR, including mobile apps, to understand the psychology of climate change. As others have noted [5,9–11], climate and environmental science has been a large focus of VR research for over three decades. Chris Dede et al., for example, developed River City to teach students about the scientific method and ecosystem science [12]. River City was largely run on desktop VR, but future iterations became more immersive [13]. Although immersive and desktop VR have nontrivial hardware differences that can lead to downstream effects (e.g. immersive VR often facilitates greater levels of presence than other modalities [14,15]), we focused on the psychological connections and outcomes of studying climate change in different virtual worlds and less on the mechanics or hardware.

A brief introduction to VR

VR can create meaningful psychological experiences because of its three primary technological affordances: presence, immersion, and embodiment [16]. *Presence* is the psychological "illusion of nonmediation" [17] and the sense of "being there" in a virtual environment [18]. When VR is done well, people suspend their belief that the world is synthetic [19]. In immersive VR, which is characterized by stereoscopic displays in headsets, controllers, sensors, and high-fidelity tracking, presence is more easily achieved compared with VR on a computer or mobile device. *Immersion* is the "technological quality" of the medium and how well the VR hardware maps to human movements [20] (p. 273). Finally, *embodiment* is the ability to change one's character or perspective in VR [21,22]. Embodiment is common in desktop VR (e.g. The Sims) [23], but its effects are particularly strong in immersive VR when considering the concurrent impact of presence and immersion [24]. For example, racial embodiment in immersive VR (versus desktop VR) provides a vivid and believable experience that one's body transferred from a particular race to another [25]. Body transfer has a well-established history in VR from a neuropsychological lens [26]. Ehrsson et al., for example, used functional magnetic resonance imaging to evaluate how the brain responded to people feeling ownership of a rubber hand [27]. Indeed, neural activity in the brain reflected feeling hand ownership that would otherwise be observed while touching a real limb.

As expected, VR affordances are complementary. A recent meta-analysis revealed that presence and immersion are moderately related (r = .316) [20]. When users feel a part of the virtual world, the technology approximates their movements appropriately and they can embody a range of characters, VR can create impactful experiences.

Psychological evaluations of climate change in VR

Drawing on the prior technological affordances, we consider recent literature evaluating psychological aspects of climate change in immersive, desktop, and mobile VR. We also describe the potential impact of embodiment on climate change effects.

Immersive VR

As many aspects of climate change, its process, and consequences are unclear to average citizens [28,29], researchers often attempt to bring the science closer and more psychologically proximate to participants [30]. Immersive VR experiences related to climate change are often positioned as field trips [31]. This, in turn, can increase participant understanding of complex ideas, engage their emotions by displaying environmental devastation, and encourage action outside of the laboratory [32].

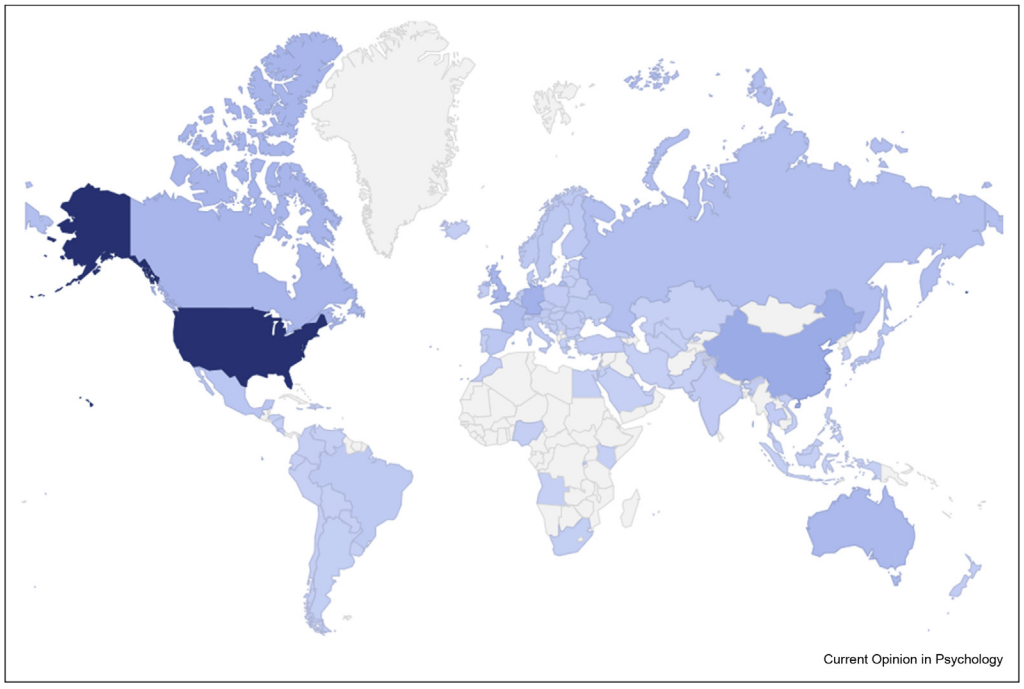
One of the first large-scale, multisite papers on immersive VR and climate change from a psychological perspective focused on education. Markowitz et al. placed high school students, university undergraduates, and adults in a virtual rocky reef affected by ocean acidification [5]. The experience took participants through the chemical processes of ocean acidification and demonstrated its effects on underwater life. In general, those who explored more of the underwater world tended to learn more about ocean acidification, suggesting interaction can assist with learning about complex science concepts. In some cases, reported levels of presence positively associated with ocean acidification knowledge and concern for the environment, indicating the more that people felt a part of the virtual world, the more they learned and connected to nature. Other studies have found similar learning gains across climate change phenomena, including water management and water conservation [33–35] and nuclear energy [36]. Immersive VR's ability to create first-hand, immediate experiences often helps to introduce new and challenging climate change topics.

Another investigation used immersive VR to simulate stormy weather patterns in Hong Kong exacerbated by the participant's electricity and energy use. When participants used more electrical appliances in the virtual world, simulations depicting their impact on Hong Kong's weather were shown in a virtual city. Therefore, the experience educated participants on the connection between high energy use and its environmental effects by bringing climate change effects closer and in a more personalized manner [37]. This evidence is consistent with psychological theories that argue behavior and attitude change can occur when people feel the impact of an experience is more concrete, immediate, and proximate [38–40].

A recent study also evaluated how presenting statistics about plastic consumption affected climate change attitudes in immersive VR [41]. Chirico et al. found that presenting plastic consumption numerically (e.g. the number of plastic water bottles consumed by 10 people per year) suppressed participant emotions toward the issue, reported levels of presence, and general attitudes toward the environment compared with a visually concrete (e.g. a pile of plastic water bottles) or mixed representation of visuals and numbers. The presentation of climate change content in immersive VR therefore affects how people feel about the issues.

Finally, virtual worlds are often built as a proof-of-concept to demonstrate climate change phenomena can be rendered in immersive VR. Simulations demonstrate the potential to examine psychological

Figure 1



People from over 100 countries have downloaded and/or used the Stanford Ocean Acidification Experience. The data in this figure represent an approximate count of all-time downloads from Steam (until September 2020) and active user count from Oculus (February 2019 to September 2020). A darker shade of blue suggests more downloads or uses than a lighter shade.

connections to climate change in VR, but they often do not measure such relationships directly. A study by Fabrika et al. [42], for example, used a CAVE Automatic Virtual Environment to place participants in a virtual forest and show the effects of tree thinning (e.g. selective tree removal). Pimentel et al. [43] had participants watch seafood become discolored and unpalatable in a virtual buffet, leveraging VR's ability to accelerate time and project climate change effects on a person's everyday life [40]. Finally, Kolb et al. [44] developed an immersive VR simulation of intense meteorological events in Bavaria, and Tibaldi et al. [45] used immersive VR to map changes in volcanology.

Researchers have scratched the surface of understanding immersive VR's potential to deliver climate change experiences and measure their psychological impact. Experimental research examines the effects of immersive VR on learning about and attitudes toward the environment, although more work is needed to understand if other immersive experiences can move past the proof-of-concept stage to affect how people feel.

Desktop and mobile VR

Desktop VR studies often examine the dynamics of effective climate change storytelling [46]. Greussing observed that knowledge acquisition suffered when a 360-degree photograph was added to a news story about climate change relative to reading the story without an image [47]. The author suggests the 360-degree photograph distracted readers from the story's content, arguing that how a story is communicated with VR technology is a crucial consideration.

Mobile VR technology, which uses a person's smartphone, has marked climate change effects longitudinally [48]. For example, La Salandra et al. built a mobile VR application to detect the deterioration of mountain peaks because of climate erosion [49]. The authors propose that their system, PeakLensVR, can be applied to more immersive technology (e.g., Gear VR) and generates an "environment that humans can interact with a sense of presence similar to that of real life" (p. 1207). Presence was not evaluated in their assessment of the virtual world, however. We expect the number of mobile VR studies to increase as smartphone access increases and as the technology continues to bring interactive, first-hand climate experiences directly to users.

Embodiment effects

There is mixed evidence related to how embodiment changes participant thoughts and feelings about climate change in VR. For example, Markowitz et al. [5] tested if embodying a coral versus a scuba diver affected learning gains about ocean acidification, but on average,

participants in both groups tended to learn about climate change at a similar rate. However, embodying a virtual cow in immersive VR changed how people felt toward nature compared with watching a video of a virtual grazing [50]. Participants who embodied a virtual cow had higher rates of reported presence and greater connectedness to nature than those in the video-watching condition. More work is required to understand how embodiment changes attitudes about climate change and the specific mechanisms that might drive these effects.

Taken together, most of the research on VR and the psychology of climate change draws on key affordances of the medium—presence, immersion, embodiment—to create experiences that make people feel differently about the environment. Studies in immersive VR use the technology as a tool for education to demonstrate climate change effects in short experiential bursts or as a proof-of-concept. Desktop and mobile VR studies are less common, but they generally attempt to uncover novel ways of delivering climate change experiences. Future work would benefit from identifying the VR experience best suited to deliver impactful climate change stories and the boundary conditions of embodiment effects on climate change attitudes.

Conclusion

The evidence in this review suggests that VR experiences can make important contributions toward understanding psychological aspects of climate science. First, VR tools can mark the progression of ecological systems affected by climate change [45,49] and increase participant interest, concern, or knowledge about the issues [5,31,33–35,37,51,52]. Climate change research in VR can also expose users to new experiences that would otherwise be impossible (e.g. people cannot accelerate time to see climate change effects), counterproductive (e.g. people should not burn fossil fuels to demonstrate heat being trapped in the atmosphere), costly (e.g. traveling to an area affected by climate change also harms the environment and requires many resources), or dangerous (e.g. wildfire training in-person can risk lives, whereas training in VR does not) in the physical world [9]. Therefore, immersive, desktop, and mobile VR can deliver meaningful climate change content and test how people think, feel, and respond to the issues.

The social and psychological impact of VR climate change research has already been felt outside the laboratory [53]. The Stanford Ocean Acidification Experience [54], for example, has been downloaded and/or used in more than half of the countries worldwide (see Figure 1). For VR and climate change experiences, we believe "if you build it, they will download," so long as the virtual world is public, free, scalable across platforms, and connects with individuals personally and presents users with new information about the climate. Users should exit a VR experience with a new appreciation for the medium and the environment affected by climate change. We encourage researchers to build virtual worlds with the goal of making them publicly available because access to reliable climate information is also an important issue [55]. Increasing knowledge about climate change mechanisms can generally help to change attitudes and environmental beliefs [56,57], and we believe that virtual experiences can amplify such effects.

Finally, although much of the psychological research on VR and climate change has focused on education, more longitudinal data should be recruited in this line of work. Other important empirical avenues include but are not limited to (1) testing how climate change deniers respond to environmental experiences in VR, (2) developing desktop VR curricula for environmental science classes and targeted training in immersive VR, (3) using lightweight VR mobile applications and tools to make environmental stories more engaging and memorable to a wide audience, and (4) providing VR developers with incentives to create virtual worlds that improve public concern for the environment. Climate change is a global issue that affects all institutions and societies. It should therefore motivate industry and academic collaborations to improve how we deliver virtual climate experiences.

Authors' contributions

D.M.M. wrote, reviewed, and edited the article. J.B. reviewed and edited the article.

Conflict of interest statement

The authors declare no conflict of interest in the creation or writing of this article. Dr Jeremy Bailenson is the founding director of the Virtual Human Interaction Lab at Stanford University, where Dr David Markowitz was a Ph.D. student.

Acknowledgements

The authors thank Tobin Asher for their assistance with creating Figure 1.

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* of special interest
** of outstanding interest

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