Virtual Reality Experiences to Promote Environmental Climate Citizenship

Monique Santoso and Jeremy Bailenson

Contents

Abstract

Virtual reality (VR) experiences have the potential to address the psychological barriers associated with climate change and are a rapidly evolving field of study. Thus far, researchers have explored how the medium's affordances of immersion, presence, and embodiment can result in psychological and behavioral changes with regard to the environment such as a greater connection to wildlife via body transfer, enhanced learning on climate change-related topics through active VR content exploration, and higher support for proenvironmental policies via immersive exposure to nature. This chapter begins with a general overview of the psychological dimensions of climate change and environmental citizenship before delving deeper into the current literature on the psychology of VR for promoting environmental citizenship through its four principles of (i) protecting nature, (ii) preserving biodiversity, (iii) adopting environment-friendly habits and

M. Santoso (✉) · J. Bailenson
Department of Communication, Stanford University, Stanford, CA, USA
e-mail: mtsantoso@stanford.edu

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behaviors, and (iv) supporting environmental policies. It concludes by outlining possible future research avenues in the intersection of the psychology of climate change mitigation and adaptation and virtual reality.

Keywords

Climate mitigation · Climate adaptation · Virtual reality · Environmental citizenship

Introduction

Addressing climate change, which involves mitigation or taking steps to lower or stop the release of greenhouse gases (GHG) that lead to anthropogenic climate change, as well as adapting to its current and anticipated impacts, stands out as one of the most pressing tasks of the twenty-first century (Kumar 2022; IPCC 2014). The Intergovernmental Panel on Climate Change emphasized that to control worldwide climate shifts, governments, industries, and communities must swiftly transform their actions to restrict temperature increases to 1.5 °C or lower (IPCC 2018). Individuals can contribute to mitigation by changing their lifestyles and behaviors, ranging from low-impact behaviors, such as recycling, to high-impact ones, such as reducing air travel (IPCC 2022). Behaviors that reduce GHG emissions and environmental harm are called proenvironmental behaviors, and they can mitigate climate change effects by 40–50% by 2050 (Tian and Liu 2022; IPCC 2022).

In a nationally representative survey of American citizens, 74% stated that climate change is happening, with 61% understanding that climate change is mainly human-induced (Leiserowitz et al. 2023). However, only 44% stated that they have personally encountered the impacts of climate change (Leiserowitz et al. 2023). Despite this, more than 50% of Americans believe this problem will negatively affect future generations of humans and plant and animal species, leading to severe consequences on both local and global scales (Leiserowitz et al. 2023). Consequently, the cultivation of environmental citizenship becomes imperative. Environmental citizenship necessitates individuals to exhibit concern for the environment, irrespective of whether they have personally experienced its visible manifestations, and to do so through individual actions and policy support.

Marked by a commitment to environmental justice for communities already grappling with the direct impacts of climate change and grassroots activism, environmental citizenship seeks to achieve several objectives: (i) enhance individual capacity for adopting environment-friendly behaviors; (ii) foster a positive orientation toward environmental concerns; (iii) raise consciousness and disseminate information about sustainable behaviors; and (iv) promote a sense of accountability in environmental governance (ENEC 2018). There are many routes individuals can take toward embracing environmental citizenship, including civic participation in addressing existing environmental challenges. This approach aims to promote sustainability through human–nature relationships while emphasizing the role of

individual actions, collaborations with societies, and active community engagement (ENEC 2018).

Building on prior literature, environmental citizenship is operationalized by the principles of (i) protecting nature, (ii) preserving biodiversity, (iii) adopting environment-friendly habits and behaviors, and (iv) supporting and participating in the creation and implementation of environmentally beneficial policies to address the psychological barriers associated with climate change (Biresselioglu et al. 2022). These barriers include but are not limited to (i) cognitive barriers, such as limited cognition of future consequences to present-day actions; (ii) affective barriers, such as a lack of concern, empathy, and respect for others from different backgrounds most affected by climate change; and (iii) sociopolitical barriers, such as a lack of in-group support of proenvironmental barriers within individual social and political affiliations (van der Linden and Weber 2021). Moreover, the literature on environmental psychology has also illustrated how personality traits influence individual likelihoods of participating in environmental behavior and engagement, wherein individuals with higher agreeableness and conscientiousness had higher links to environmental behavior and engagement (Poškus and Žukauskienė 2017; Milfont and Sibley 2012).

What Is Virtual Reality?

Although virtual reality (VR) has been present since 1968, the scientific inquiry into VR as a window into people's physical and psychological states has recently become popular among researchers. In medicine alone, publications on VR reached 100 by 2005 and exceeded 1000 by 2018 (Yeung et al. 2021). This can be attributed to the technological evolution of VR technology that has resulted in relatively low-cost hardware and increased portability (Aitamurto et al. 2021). Parallel to this is the increasing ease of production and publication of VR content through platforms such as YouTube Virtual Reality.

The global market for VR headsets is predicted to reach USD 435.36 billion by 2030 (Grand View Research 2023). Over the last decade, scholarly interest has also grown in how and why immersive VR can change environmental attitudes and behavior for its ability to provide real and personal experiences of distant biospheres through virtual worlds and overcome the psychological barriers to climate action. Especially given the ongoing conversations about the Metaverse and the presence of humans in virtual environments, this is a timely question for scholars and practitioners alike.

Virtual reality is a blanket term that connotes different technologies that display digital environments (Mado and Bailenson 2022). These technologies range from desktop computers and mobile phones, flight and driving simulators to fully immersive cave automatic virtual environment (CAVE) systems and head-mounted displays (HMD) (Tarr and Warren 2002). Using specialized hardware, such as an HMD, hand controllers, stereoscopic sound, and haptic feedback or CAVE that employs multiple walls to project imagery, VR creates "synthetic sensory

information that leads to perceptions of environments and their contents as if they were not synthetic" (Blascovich et al. 2002). In other words, virtual reality generates an immersive virtual environment that surrounds users, presenting the virtual world in a manner that closely resembles the physical world, triggering a physiological response as though the virtual environment was real. This allows researchers to offer a highly immersive avenue for individuals who might not have the chance to engage in climate change-related experiences to undergo such personally.

In an immersive virtual environment (IVE), users experience a psychological presence of being within the virtual environment, wherein the virtual surroundings envelop them and thus become the realm they inhabit at that moment. To understand the psychological mechanisms at play in an IVE, it is essential to understand three psychological constructs: presence, immersion, and embodiment (Mütterlein 2018). Presence is divided into three types. *Spatial presence* is the extent to which one believes oneself to be experiencing physical entities and environments when engaging with the virtual environment (Witmer and Singer 1998). High spatial presence implies that users are no longer aware of the immediate physical environment and temporarily forget that the virtual environment is mediated. *Personal or self-presence* refers to the experience of one's self as existing in a virtual environment (Heeter 1992; Lee 2004). Users with a strong sense of self-presence perceive their virtual self as their physical self (Aymerich-Franch et al. 2012). Finally, *social presence* is the extent to which one perceives oneself to be with others and has access to the sensory experience and mental considerations of others (Biocca 1997). Social presence allows users to perceive others as "being there" with them. For instance, the subjective feeling of presence makes the VR user of an animal experience in an empty room feel as though they are in a virtual pasture (Ahn et al. 2016).

Immersion is determined by how effectively VR technology replicates everyday human actions and behaviors (Cummings and Bailenson 2016). For VR experiences to be perceived as real, the technology must accurately track head, hand, and body movements and render them on screen without delays or distortions. Immersion and presence are closely interconnected, as studies have indicated that VR experiences with better tracking, rendering, and stereoscopic visuals offer a more psychologically rich experience than less immersive experiences (Cummings and Bailenson 2016).

The third aspect is embodiment, involving the visual representation of the virtual self, ranging from virtual hand representation to full-body avatars (Heeter 1992; Kilteni et al. 2012). Research into embodiment and attitude change has found that embodiment leads to more direct and personal experiences than secondhand experiences and is more likely to influence proenvironmental behavior (Ahn et al. 2014). The Proteus Effect delineates how users assimilate attributes of the avatar they inhibit (Yee and Bailenson 2007). To illustrate, Yee and Bailenson (2007) found that embodying a tall avatar elicits leads to more confident behavior compared to embodying a shorter avatar. Research conducted by Ahn et al. (2016) further elucidates that embodying sensory experiences of animals in VR fosters an increased connection between oneself and nature outside of the IVE. This, in turn, generates

stronger perceptions of the proximity of environmental risk and increases one's involvement with nature for a week following the IVE.

Another novel aspect of VR is its ability to take on another person's perspective, or VR perspective-taking (VRPT). A study by Herrera et al. (2018) illustrated that participants who took on a homeless person's perspective in VR felt more empathy and connection to people experiencing homelessness than those in the traditional, narrative-based perspective-taking task. Nevertheless, VRPT is contingent upon the target and context. For example, in a study by Mado et al. (2021), it was found that while engaging in a VRPT task related to ocean acidification could enhance empathy for homeless individuals as an unrelated social target, this empathy transfer effect was not observed when transitioning from the context of homelessness to the ocean task. This finding has implications for empathy and conservation work, as it signifies that embodiment in a particular task may enhance specific altruistic outcomes and the importance of embodying an "appropriate" body for the task at hand.

Virtual reality achieves these affordances through a cycle of tracking, rendering, and display (Niehorster et al. 2017; El Beheiry et al. 2019). *Tracking* refers to measuring the user's body positions and head movements. For instance, when a user walks forward and looks to their right, the displacement in body position and head movement rotations are measured. *Rendering* implies translating tracking information to update the virtual scene with the appropriate sights, sounds, and, at times, touch or smell. When users walk toward an object in the virtual environment, their viewpoint changes, and the object becomes closer and closer. *Display* is how digital information in rendered sights, sounds, haptics, and smells are delivered to the user. For example, when an individual dons an HMD system, it blocks out the sights and sounds of the physical world and replaces them with stereoscopic images (Bailenson 2018).

Virtual Reality for Promoting Proenvironmental Behavior

Markowitz and Bailenson (2021) discussed using VR for climate change education and promoting proenvironmental behaviors, highlighting key reasons why the medium is particularly adept at understanding the psychological aspects of climate science. This is because the medium can provide users with novel experiences that would otherwise be (i) dangerous, such as understanding the emotional effects of those affected by earthquakes, (ii) impossible, such as one's ability to accelerate time to understand the influence of individual actions on climate change effects, (iii) counterproductive, such as the burning of fossil fuels to demonstrate greenhouse gas emissions, or (iv) expensive, such as flying to a remote island affected by flooding, which follows the DICE framework (Bailenson 2018). In addition, the review drew on the importance of creating VR experiences that are public, free, and scalable across platforms to increase knowledge on climate change and its mechanisms, such as the Stanford Ocean Acidification Experience, one which finishes up with policy recommendations that have been presented to the US Senate (Virtual Human Interaction Lab 2016; Jordan 2016).

Additionally, Fauville et al. (2020) reviewed 13 studies on the state of research in the VR field for environmental literacy to promote climate change awareness. The authors highlight that while studies have reported positive outcomes of using VR for environmental literacy, studies still need to measure environmental competencies or all four dimensions of the environmental literacy framework (knowledge, dispositions, competencies, behavior) together. This indicates that research on VR for promoting environmental literacy is still in its infancy, and future directions elicited from the review include understanding the features of VR that make it practical for environmental literacy, as well as the timeframe for VR effects on subjects' pro-environmental behavior.

In this chapter, we will review the field of virtual reality for the psychology of climate change to promote environmental citizenship and discuss the potential for future VR applications and research. To accomplish this aim, we collected studies from the following online databases: PubMed, Google Scholar, Springer, IEEE, and ACM. After an exploratory search, the following search terms were defined. They included a combination of the following: "virtual reality," "immersive VR," "virtual environment technologies," "immersive virtual environment," "IVE," "VR," "head-mounted display," "climate change," "global warming," "sustainability," "environmental behavior," "climate mitiga*," "climate adapt*," "environmental," "environmental citizen*," and "proenvironmental behavior." Only empirical, peer-reviewed journal articles that used head tracking via an HMD setup, contained a behavior change intervention for proenvironmental behavior, and were published within the last 5 years were reviewed. The decision to start the review with papers published in 2018 focused on current trends in virtual reality and proenvironmental behavior rather than delve into historical trends. While semi-immersive cave automatic virtual environment (CAVE) and nonimmersive media such as desktops and smartphones have been used as tools to promote environmental citizenship (Fabrika et al. 2018; Soliman et al. 2017), they vary differently in effect depending on participant point of view, spatial presence and immersion measures, and realism to immersive VR (Ventura et al. 2019). A handful of studies discussed below compare the efficacy of immersive VR and nonimmersive VR systems to illustrate the differences in media effects (Walewijns et al. 2023; Ball 2023). To focus on immersion and body/hand interaction in IVR, we limited the studies below to those using an HMD, hand controllers, stereoscopic sound, and haptic feedback, including those where participants viewed 360 videos in an HMD.

Of note are the differences between 360-degree videos and IVR. While they can both be viewed in an HMD, 360-degree videos are immersive, spherical video recordings captured using an omnidirectional camera and can project a postproduction view in every direction simultaneously (Hildenbrand 2021). User interactivity is limited, such that users cannot move around within the video and cannot interact directly with objects. It is mostly used in virtual tours and immersive storytelling. IVR, on the other hand, uses high-end graphics and visuals to recreate scenes of high fidelity. In IVR, users are active participants in their experiences. They can change their viewing angles and locations using their controller, as well as interact with scene objects inside the experience (Hildenbrand 2021).

The 30 papers included in this review are summarized and categorized into the four principles of environmental citizenship (Biresselioglu et al. 2022) (Table 1):

- Protecting Nature: This principle suggests that environmental citizens keep the environment safe by protecting the livelihood of humans and wildlife alike in vital places of the planet through actions such as decreasing carbon footprints and reducing waste.
- Preserving Biodiversity: This concept revolves around safeguarding the environment from harm and deterioration by preserving plant and animal life, discontinuing the utilization of harmful chemicals, and implementing practices such as regenerative agriculture.
- Adopting Habits and Behaviors: Embodying environmental citizenship involves embracing behaviors and routines that support the environment, such as recycling, conserving energy and water, and selecting products with reduced carbon footprints.
- Policy Support: This dimension includes individuals' participation, empowerment, and responsibility for engaging in environment-related decision-making and policymaking, such as supporting proenvironmental policies and participating in policy formulation. Policy support could be understood as a positive spillover behavior from engaging in environmental habits and behaviors, as individuals like to be consistent with their actions (Graves and Roelich 2021).

Notably, environmental citizenship is not divided into discreet conditions along the four principles, and each is related to another. The first three sections present the findings from empirical investigations in three of four environmental citizenship principles: preserving biodiversity, adopting habits and behaviors, and providing policy support. Specifically, we review how people engage with climate change mitigation and adaptation issues in VR and outside the VR environment. In each section, we link perspectives from the psychology of climate change and virtual reality affordances to provide an integrative understanding of VR for promoting environmental citizenship. There was no section for protecting nature because no publications addressed this principle through VR. In the last section, we indicate the limitations of current research and suggest future directions for using VR to promote environmental citizenship.

Virtual Reality for Preserving Biodiversity

This section details how virtual reality can increase the preservation of diversity. *Preserving biodiversity* is defined as conserving, uplifting, and managing biodiversity to maintain it at its threshold levels while still deriving sustainable benefits for the present and future generations (Jaisankar et al. 2018). One of the challenges of promoting behaviors that preserve biodiversity is the psychological distance experienced by individuals on the issue (Bosone et al. 2022). That is, while individuals are aware of the need to preserve biodiversity, conservation efforts often happen

Table 1 Summary of studies categorized by environmental citizenship principles

#	Author/ department	Year	Environmental citizenship principle	Country	Sample	Research goals	Data collection	Environmental citizenship outcomes	Factors affecting outcome
1.	Chirico et al., Psychology	2023	Adopting habits and behaviors	Italy	119 adults	To compare the pro-environmental effectiveness of VR-based awe-inspiring versus non-awe-inspiring virtual scenarios either featuring natural stimuli or non-natural stimuli	(1) Emotions (2) General Attitudes toward the Environment and Attitudes toward plastic waste and consumption (3) Attitudes toward plastic use (4) Behavioral intentions toward recycling, consumption, and waste of plastic (5) Social desirability (6) Actual pro-environmental behavior (7) Connectedness to nature (8) Environmental behaviors (9) Environmental sacrifice	Awe-inspiring virtual nature increased the number of flyers taken (socially engaging behavior) compared to the control of non-natural non-awe-inspiring nature	Awe-inspiring virtual nature (tall trees)
2.	Kleinlogel et al., Business and Economics	2023	Adopting habits and behaviors	Switzerland	234 students	To compare the effectiveness of different formats of conducting	(1) Energy saving attitudes (2) Perceived social norms	Receiving pro-environmental knowledge in virtual reality led	Presence mechanism, active engagement to

						promotional campaigns providing pro-environmental knowledge	(3) Energy saving strategies	to more energy-saving attitudes and different use of products and appliances at home compared to traditional media	material in VR, and the experiential aspect of learning new behaviors in virtual reality
3.	Mol et al., Economics	2023	Adopting habits and behaviors	Netherlands	130 participants	To examine whether a simulated disaster in VR can stimulate people to invest in risk reducing measures for flooding.	(1) Risk perception (2) Coping appraisal (3) Negative Emotions (4) Damage reducing behavior (5) Presence (6) Visually induced motion sickness (VIMS)	Participating in a virtual flood experience increases risk perceptions, investment in damage-reducing measures in a flood risk investment game compared to the control (no exposure to virtual flood)	Severity of VR flood, worry about flooding after VR experience
4.	Walewijns et al., Communication	2023	Adopting habits and behaviors	Belgium	150 young adults	To understand how VR technology can be used to elicit more donations for charitable environmental organizations	(1) Spatial presence (2) Empathy (3) Responsibility and guilt (4) Issue involvement (5) Donation intention (6) Donation behavior	Viewing 360-degree videos in VR increased donation intentions but not actual donations	Empathy
5.	Ball, Communication	2023	Adopting habits and behaviors	USA	66 college students	To explore how VR could be an avenue for more environmentally friendly nature	(1) Environmental attitudes and behavioral intentions (2) Connectedness to nature	No significant influence of VR travel condition on environmental	Spatial presence, narrative engagement

(continued)

Table 1 (continued)

#	Author/ department	Year	Environmental citizenship principle	Country	Sample	Research goals	Data collection	Environmental citizenship outcomes	Factors affecting outcome
						tourism and increase environmental connectedness and consciousness compared to traditional 2D videos	(3) Environmental activism intentions (4) Ocean protection attitudes	connectedness and consciousness	
6.	Stenberdt & Makransky, Psychology	2023	Adopting habits and behaviors	Denmark	138 participants	To investigate the feasibility of a VR educational experience on improving waste management in the classroom as part of formal education by utilizing mastery experiences in VR.	(1) Knowledge (2) Intentions (3) Transfer (4) Waste sorting (5) Self-efficacy (6) Response efficacy	The VR simulation increased knowledge of waste management	Self-efficacy
7.	Meijers et al., Communication	2023	Adopting habits and behaviors	Netherlands	278 participants	To investigate whether experiencing climate change consequences virtually can influence cognitions, emotions, and	(1) Spatial presence (2) Emotional responses (3) Risk perceptions (4) Psychological distance (5) Intentions to reduce meat and dairy consumption (6) Donation behavior	VR experience of a wildfire have higher spatial presence, emotional response. Spatial presence influenced risk perceptions and	Spatial presence, risk perception, emotional response

						pro-environmental intentions and behaviors	(7) Food choice measure	negative emotional responses. Higher negative emotions were experienced in the VR condition than the desktop video and the control. Increased spatial presence in VR and video had higher risk perception and emotional response and subsequently influenced intentions to reduce meat and dietary conditions than the articles only condition	
8.	van Gevelt et al., Urban Sustainability	2023	Adopting habits and behaviors	Hong Kong	1507 students	To test the efficacy of virtual simulations of future extreme weather events to communicate risk of climate change	(1) Climate change knowledge (2) Personal experience with typhoons (3) Social norms and value orientations (4) Risk Perceptions of climate change (5) Modified dictator game to generate observable	VR simulations of future extreme weather decreased climate change risk perceptions.	Climate change skepticism, motivation crowding, geographical and temporal distance, high-risk thresholds, feelings of hopelessness, concerns

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Table 1 (continued)

#	Author/ department	Year	Environmental citizenship principle	Country	Sample	Research goals	Data collection	Environmental citizenship outcomes	Factors affecting outcome
							data for climate mitigation		surrounding immersiveness
9.	Queiroz et al., Communication	2023	Adopting habits and behaviors	USA, Denmark, Canada, UK	305 participants	To investigate the effect of content segmentation, presence, standing-up experience on learning, behavior, risk perception, concern, causes, and beliefs about increased carbon dioxide emissions, presence, self-efficacy, and trust	(1) Head and body tracking (2) Knowledge and learning gains (3) Environmental behavior (4) Concern for ocean health (5) Risk perception (6) Beliefs (7) Causes of climate change (8) Self-efficacy (9) Presence (10) Trust	Learning about ocean acidification increases climate change behavior. Trust in information received in VR indirectly influenced behavior via risk perception. When experiencing VR seated, head yaw positively affected learning, while hands' pitch and yaw hindered learning. Head translation increased self-efficacy but hindered learning.	Trust, risk perception, beliefs
10.	Queiroz et al., Communication	2023	Adopting habits and behaviors	USA	Study 1: 53 eight-grade female students	To study the effects of educational VR versus traditional videos on	(1) Presence (2) Open-ended learning assessment questions (3) Multiple-choice	No differences in multiple-choice scores in assessing conceptual	Immersion, learning agency, self-efficacy

					Study 2: 139 sixth-to-eighth grade female students	conceptual knowledge and self-efficacy	learning assessment (4) Self-efficacy and motivation to learn science	knowledge in Study 1. Participants in the IVR group scored higher for knowledge creation than in the desktop group in Study 2. Participants had higher self-efficacy in the VR group than the desktop group in Study 1 but not Study 2	
11.	Plechatá et al., Psychology	2022	Adopting habits and behaviors	Denmark	90 middle school students	To investigate the impact of an efficacy-focused virtual reality (VR) intervention designed according to instructional design principles on eating behavior.	(1) Knowledge (2) Change in dietary carbon footprint (3) Behavioral intentions (4) Self-Efficacy (5) Response Efficacy (6) Psychological distance (7) Pre-existing knowledge (8) Reported dietary lifestyle	The VR condition elicited a decrease in dietary footprint from 1-week prior to 1-week after the intervention and increased response-efficacy and knowledge	Locus of control, interactivity
12.	Plechatá et al., Psychology	2022	Adopting habits and behaviors	Denmark	123 participants	To investigate the impact of an efficacy-focused virtual reality (VR) intervention	(1) Knowledge (2) Change in dietary carbon footprint (3) Self-efficacy	There is a significant change between the VR and control conditions on	Psychological distance, normative feedback, self-efficacy

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Table 1 (continued)

#	Author/ department	Year	Environmental citizenship principle	Country	Sample	Research goals	Data collection	Environmental citizenship outcomes	Factors affecting outcome
						designed according to instructional design principles on eating behavior	(4) Psychological distance	average change in dietary footprint. The VR intervention has higher knowledge gains than the control	
13.	Pimentel & Kalyanaraman, Communication	2022	Preserving biodiversity	USA	273 participants	To investigate whether experiencing climate change consequences in VR can influence cognitions, emotions, and pro-environmental intentions and behaviors	(1) Body transfer (2) Spatial presence (3) Social copresence (4) Environmentalism (5) Pro-environmental behavior intentions (6) Donations (7) Attitude toward environmental public service announcement	Viewing PSA from seven victims led to less donations for sea turtle conservation than those who viewed PSA for one victim, demonstrating compassion fade. Embodying threatened wildlife in VR can reverse compassion fade and the effect is contingent upon victim similarity. Donations are greater among those who encountered	Hapticity, similarity of victims, strength of body transfer

								several similar victims as opposed to one similar victim. Increased threat perceptions lead to greater donation intentions	
14.	Hofman et al., Business	2021	Preserving biodiversity	Australia	114 participants	To compare the impact of a real versus a virtual nature-based marine tourism experience on participants' intentions to engage in conservation behaviors.	(1) Commitment to the environment (2) Frequency of conservation Behaviors (3) Environmental concern about the planet (4) Emotional connection with marine environments	VR nature-based experiences targeting behavior change can be as effective as real experiences with nature	Sense of connectedness, Emotional connection
15.	Calil et al., Ocean Sciences	2021	Policy support	USA	149 participants	To provide an account of how three coastal communities have used VR experiences to support communication and community outreach on sea level rise	(1) Coastal management related questions (2) Awareness of sea-level rise due to VR experience	Participants in VR showed greater awareness of sea-level rise, they agreed on a near-term solution for sea-level rise	Hyper-realistic visualizations of sea-level rise in VR, narrative framing
16.	Breves & Schramm, Communication	2021	Preserving Biodiversity	Germany	112 volunteers	To test the efficacy of VR in decreasing	(1) Spatial presence experience (2) Knowledge	Immersive VR reduced temporal psychological	Immersion

(continued)

Table 1 (continued)

#	Author/ department	Year	Environmental citizenship principle	Country	Sample	Research goals	Data collection	Environmental citizenship outcomes	Factors affecting outcome
						individuals' psychological distance and increasing personal relevance, as well as perceived risk intentions concerning environmental behavior and risk perceptions	(3) Pro-environmental behavior intentions (4) Spatial and temporal distance	distance and increased perceived risk severity both after watching the video and 10 days later	
17.	Deringer & Hanley, Health and Human Performance	2021	Policy support	USA	57 participants	To understand the relationship between virtual nature experiences and ecological behavior	(1) Environmental behavior (2) Nature connectedness (3) Inclusion of nature in self	VR nature acts as an alternative method of experiencing high use for endangered areas and as a conservation tool with those who experienced VR nature having positive environmental behavior	Experimental nature condition
18.	Chirico et al., Psychology	2021	Adopting habits and behaviors	Italy	172 students	To test which the best way to present statistical evidence	(1) Sense of presence (2) Specific attitudes toward recycling,	Mixed format statistical representation in	Emotions

						about plastic consumption in VR for promoting attitude and behavior intention change is and to represent statistical evidence concerns using a visual representation of the corresponding amount	wasting, plastic consumption (3) Individual behavioral intentions toward plastic waste and consumption (4) General attitudes toward the environment (5) General affect and discrete emotions (6) Social desirability	VR resulted in the best at conveying positive attitudes toward waste and consumption but did not differ from the concrete condition	
19.	Raja & Carrico, Communication	2021	Adopting habits and behaviors	Netherlands	277 participants	To investigate whether experiencing climate change consequences virtually can influence cognitions, emotions, and pro-environmental intentions and behaviors	(1) Perceived psychological distance (2) Experience qualities (3) Emotional responses	Participants reported feeling psychologically close to ocean acidification	Presence, flow, realism, vividness
20.	Meijers et al., Communication	2022	Adopting habits and behaviors	Netherlands	265 participants	To increase personal response efficacy beliefs by using virtual reality for environmental choice	(1) Behavior change (2) Personal and collective response efficacy (3) Realism	Impact messages popping at the time of decision-making would lead to more environmentally friendly food choices. Both environmental and	Personal response efficacy beliefs

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Table 1 (continued)

#	Author/ department	Year	Environmental citizenship principle	Country	Sample	Research goals	Data collection	Environmental citizenship outcomes	Factors affecting outcome
								health impact messages were effective. However, seeing impact messages in the VR supermarket did not lead to more environmentally food product choices in daily life. The effects lasted for 2 weeks	
21.	Smit et al., Communication	2021	Adopting habits and behaviors	Netherlands	25 children	To study the effectiveness and user experience of VR application that educate children about health and sustainability as it relates to food consumption	Qualitative interview study with responses analyzed by the framework method	When participants understood the information, they were aware and often sorry about their negative behavioral impact. Participants expected positive change in their behavior on imagining real-life application of pop-ups	Understanding of content being displayed about health and environmental effects of the product

22.	Oh et al., Communication	2021	Adopting habits and behaviors	USA	119 students	To study the persuasive impact of 360-degree environmental messages compared to unidirectional videos in VR on engagement with global warming.	(1) Perceived interactivity (2) Sense of control (3) Visual appeal (4) Emotions (5) Global warming engagement (6) Elaborated processing (7) Beliefs about global warming (8) Environmental self-efficacy (9) Arousal	Interacting with the 360-degree feature elicited less fear arousal, enhanced and feelings of contentment compared to unidirectional videos in VR. Increased contentment and decreased fear arousal were associated with less engagement in the global warming issue	Presence, usage of 360-degree feature, interaction, contentment, emotion
23.	Petersen et al., Psychology	2020	Adopting habits and behaviors	Denmark	102 students	To investigate how VR could increase interest in climate change, STEM intentions, and knowledge from pre- to post-test	(1) Knowledge (2) Behavior change intentions (3) Self-Efficacy (4) Interest (5) Outcome expectations (6) STEM intentions (7) Knowledge transfer	VR climate education led to significant improvements in environmental behavior change intentions pre- to post-assessment. Pre-training increases student knowledge transfer as opposed to training given during immersive VR experience	Self-efficacy, positive outcome expectations

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#	Author/ department	Year	Environmental citizenship principle	Country	Sample	Research goals	Data collection	Environmental citizenship outcomes	Factors affecting outcome
24.	Oh et al., Communication	2020	Adopting habits and behaviors	USA	76 students	To compare pro-environmental 360-degree videos and unidirectional videos in their persuasive effectiveness for environmental self-efficacy and intentions to protect the environment	(1) Behavioral intentions (2) Environmental self-efficacy (3) Perceived interactivity (4) Perceived fun and credibility of video content	360-degree VR video experiences increased engagement and intentions to protect the environment	Self-efficacy, user engagement
25.	Nelson et al., Economics	2020	Adopting habits and behaviors	Indonesia	1006 participants	To investigate the effects of varying degrees of visual immersion and positive versus negative message framing on respondents' contributions to an environmental conservation charity	(1) Presence (2) Donation to an environmental charity (3) Environmental engagement (4) Personal perspectives (5) Religiosity	VR conditions were more effective in increasing average contribution amounts compared to no media communication	Immersion
26.	Filter et al., Biology	2020	Preserving biodiversity	Germany	50 students	To explore how VR could increase environmental attitudes,	(1) Spatial presence experience scale (2) Attitudes toward	Increased immersion was related to increased sense of presence.	Immersion, presence, interest, emotions,

						particularly toward wolf conservation	wolves (3) Emotional reactions	The VR viewing condition had significantly higher interest compared to the 2D viewing condition. Higher interest resulting in most positive attitudes toward wolves and less fear for them	existing attitudes
27.	Breves & Heber, Communication	2019	Adopting habits and behaviors	Germany	56 participants	To investigate whether viewing immersive 360-degree nature videos in VR can influence individuals' commitment to the environment	(1) Spatial Presence (2) Need for affect (3) Environmental connectedness	Immersive nature videos led to higher levels of spatial presence and commitment to the environment	Need for affect
28.	Liu et al., Political Science	2019	Adopting habits and behaviors	China	360 volunteers	To examine the use of VR for strengthening environmental literacy	(1) Environmental moral education level (2) Environmental ethics (3) Environmental literacy	VR experiences increase interest, learning, and promoted environmental ethics and environmental action	Environmental ethics, Environmental education
29.	Hsu et al., Civil Engineering	2018	Adopting habits and behaviors	Taiwan	165 players	To utilize immersive virtual environment technology and	(1) Cognition of daily water consumption (2) Attitude toward water usage (3) Self-	Vivid and personally relevant VR experiences increase	Vividness, personal relevance

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Table 1 (continued)

#	Author/ department	Year	Environmental citizenship principle	Country	Sample	Research goals	Data collection	Environmental citizenship outcomes	Factors affecting outcome
						create VR experiences that expose individuals to vivid information with personal relevance and immediacy in hopes of increasing water conservation behaviors	reported behavior intention to conserve water (4) Extent of tightening of the virtual faucet and (5) Presence in the virtual environment	environmental cognition, attitude, and behavioral intentions	
30.	Markowitz et al., Communication	2018	Adopting habits and behaviors	USA	270 students	To test the efficacy of immersive VR as an education medium for teaching about the consequences of climate change, particularly ocean acidification	(1) Learning gain (2) Tracking data about movement in VR (3) Qualitative responses from teachers (4) Presence (5) Environmental attitudes and behaviors	Participants report positive knowledge gain and interest in learning about the cause and effects of ocean acidification after immersive VR experiences. Participants who explored, travelled, and found more marine objects demonstrated higher learning about climate change	Time in dive, presence, connectedness to nature, environmental attitudes, inquisitiveness, distance travelled underwater in VR

outside one's immediate physical area. Therefore, they are unable to see the effects of their actions on conservation. VR technology has garnered interest due to its capacity to increase immersion and foster a sense of presence by influencing emotions and establishing a direct connection between individuals and the subject matter of biodiversity conservation (Nelson et al. 2020).

Wildlife embodiment is among the capabilities of virtual reality that lends itself to preserving biodiversity. Pimentel and Kalyanaraman (2022) examined the impact of immersing individuals in the role of threatened megafauna—specifically, loggerhead sea turtles—using VR as a strategy to counteract "compassion fade." This phenomenon refers to the challenge of forming empathetic connections when faced with large numbers of unfamiliar entities compared to individual victims. In the initial phase of a four-part study, 60 participants were randomly divided into two groups (victim count: one or seven) to explore the hypothesis that compassion fade could be observed within the context of an immersive representation of mass casualties. They engaged with and assessed an immersive public service announcement (PSA) that discussed the threat to loggerhead sea turtles in a hospital setting, featuring one or seven species members. The findings revealed compassion fade, wherein participants exposed to the PSA with seven victims contributed less to sea turtle conservation efforts than those who viewed the PSA featuring one victim.

In the subsequent phase of their study, the researchers examined the influence of two primary sensorimotor factors on body transfer involving a sea turtle form within a VR environment focused on sea turtle conservation. Using VR, they assigned 98 participants to one of four conditions, manipulating visuomotor representation (representation vs. no representation) and visuotactile stimulation (stimulation vs. no stimulation). Within the visuomotor representation scenarios, participants either inhabited the body of a loggerhead sea turtle, observing their movements mirrored by their sea turtle avatar (representation), or they experienced a state of disembodiment (no representation). As for visuotactile stimulation, participants were subjected to haptic vibrations corresponding to in-game events (stimulations) or did not receive any haptic feedback (no stimulation). However, there were no significant variations in self-reported environmental concern, feelings of spatial presence, and the sense of copresence among both sets of participants exposed to visuomotor representation. Moreover, no primary effects attributed to visuomotor representation or visuotactile stimulation about the phenomenon of body transfer were identified.

In the third segment of their research, 90 individuals visiting a museum were subjected to one of three scenarios, each involving either a single individual, seven individuals, or themself. This approach aimed to investigate whether the impact of animal embodiment on participants' emotional, cognitive, and behavioral reactions toward an environmental disaster would differ based on the number of victims involved, a phenomenon referred to as compassion fade. Notably, the number of victims did not exhibit any significant primary effects on the extent of environmental donations. However, a notable finding was that body transfer had a significant predictive influence on the hypothetical donation sums.

In the final phase of their investigation, the researchers divided 25 participants into one of four scenarios (victim count: one vs. seven x victim species: similar vs. dissimilar) to scrutinize the intricate relationship among body transfer, victim similarity, and compassion fade. Given that loggerhead sea turtles were identified as the similar victims, bottlenose dolphins were selected as the dissimilar species to understand compassion fade across different victim species. The results revealed that human participants contributed more toward marine conservation when exposed to numerous victims of the same species than a solitary identifiable victim of the same species. Conversely, this pattern was reversed for different species. This implies that embodying threatened wildlife within a VR setting can counteract compassion fade, yet this outcome hinges on the degree of similarity between the victims.

Another advantage virtual reality provides in mitigating psychological distance is the heightened sense of spatial presence. Filter et al. (2020) conducted a research study that contrasted the effects of 360 videos in HMD and desktop videos on wolf conservation, revealing that VR induced a greater sense of spatial presence and stronger feelings of interest than desktop videos. Despite the potential of VR to offer nature encounters with beneficial emotional learning results, the study concluded that no significant correlation existed between heightened interest levels and more favorable attitudes toward wolves.

Another investigation, led by Hofman et al. (2021), explored the influence of immersive virtual reality (VR) encounters centered around nature-based tourism on conservation-oriented actions. As previously alluded, immersion refers to VR's ability to (i) shut out physical reality from the senses, (ii) activate an extensive range of sensory modalities, (iii) surround the use with a panoramic rather than narrow field of view, (iv) provide high fidelity, resolution, and richness of display, and (v) allow the user to represent themselves with a virtual body, and match their movements with the visual and auditory display of information (Slater and Wilbur 1997). These affordances are particularly important in fostering mitigation and adaptation behaviors because they decrease psychological distance and increase the immediacy of climate change's spatial and temporal consequences. Consequently, the researchers examined the disparity in the impact of a physical in-person experience versus an immersive VR marine nature encounter on participants' intentions to partake in conservation actions. By randomly assigning 114 participants to either a 360-degree VR scenario or an actual visit to the Great Barrier Reef, the study determined no significant differences in conservation behaviors between a real-life and a virtual snorkeling experience. Notably, emotional connection influenced educational and political involvement in the virtual snorkeling setting, whereas this trend was not observed in real-world settings.

In a comparable investigation conducted by Breves and Heber (2019), scholars examined whether immersive VR nature videos can influence individual commitment to the environment compared to regular nature videos, attributed to increased spatial presence. To do so, 56 participants were randomly allocated to the 2D desktop or immersive 360-degree nature videos. The study found that compared to the 2D desktop nature videos, the immersive nature videos generated a higher sense of spatial presence and evoked greater levels of environmental connectedness.

These studies indicate that VR can encourage biodiversity preservation through human–animal body transfer and victim similarity. Moreover, the medium's capacity to heighten spatial presence while increasing emotional connection could increase educational and political involvement in conservation-related issues compared to traditional media, such as 2D desktop videos and public service announcements.

Virtual Reality for Adopting Habits and Behaviors

This section describes how VR can promote adopting environmental habits and behaviors. Adopting more environmental habits and behaviors is critical to mitigate and adapt to climate change. Existing research has concluded that risk perception, attitudes, and emotions are some of the reasons individuals adopt or do not adopt environmental habits and behaviors (Weber 2018; Wyss et al. 2022; Coelho et al. 2017). For instance, new knowledge about plant-based diets could be blocked due to existing emotional attachment toward meat, leading to the gap between attitude, intention, and behavior (Coelho et al. 2017). Recent VR studies below have targeted emotions, attitudes, risk perception, and attachment through immersion, spatial presence, knowledge provision, and perspective-taking.

Affect, Virtual Reality, and Proenvironmental Behavior

Meijers et al. (2023) investigated whether experiencing climate change consequences in VR can influence cognitions, emotions, and proenvironmental intentions and behaviors in 277 participants. To further explore the impact of technological immersiveness on their dependent variables, participants experienced a wildfire through different media, namely, VR, 2D desktop video, and magazine articles. Their study illustrated that compared to 2D desktop video and magazine articles, participants randomly assigned to the VR condition experienced higher spatial presence, stronger emotional responses, and stronger bodily responses. They reported the experience to be more lifelike. Consequently, higher spatial presence was associated with increased risk perceptions and negative effects of climate change. However, results showed that there was only an indirect effect of virtual reality and regular video vs. the article-only condition on donations to environmental nongovernmental organizations and meat and dairy consumption via increased spatial presence and risk perceptions, but not for emotions.

Nelson et al. (2020) investigated the potential for VR to promote proenvironmental behavior via increased empathy. Their research utilized field experiments to examine the impacts of different levels of visual immersion and the framing of messages (positive vs. negative) on contributions to a marine conservation charity. Study participants were randomly assigned to one of five conditions: unidirectional video featuring positive message frames, unidirectional video featuring negative message frames, 360-degree videos captured with omnidirectional cameras and incorporating positive message frames, 360-degree videos with

omnidirectional cameras and negative message frames, and a control group with no video exposure. In their first experiment, 487 students and 248 members of the public were recruited. Following the 5-min video or no video, participants completed a questionnaire on emotional experience, sense of presence, environmental engagement, personal perspectives, and a donation request. No significant differences were found across four experimental conditions, all significantly higher than the control. No significant differences between positive and negative framing or between high and low visual immersion were found. In their second experiment, 271 participants were recruited from a popular diving and tourism island. Participants completed identical survey measures and the donation request. The donation was significantly higher in all video conditions compared to the control condition. Individual differences in age and distance of living from the coast influenced donation amounts, with those older and living further from the coast donating higher amounts. Videos with high immersion elicited more donations than those with low immersion and the control, with the highest scores of presence and emotion in the omnidirectional VR treatment. No significant differences were found between videos with positive and negative framing, suggesting that emotional responses may not trigger pro-environmental action. This study's combined findings illustrate the greater nuances present when using VR for climate communication, the relative infancy of research in message framing effects in VR, and the potential for VR to drive pro-environmental action.

In a recent study by Chirico et al. (2023), researchers explored how virtual nature exposure can elicit proenvironmental behaviors via emotions, namely awe, by randomly placing 119 participants into 1 of 4 VR environments, namely (1) awe-inspiring virtual nature (a VR environment with nature composed of tall trees culminating in a downfall), (2) nonnatural awe-inspiring virtual scenario (a view of the Earth from outside the atmosphere), (3) nonawe-inspiring virtual nature (green clearing with flowers and hills), and (4) nonnatural awe-inspiring scenario (closed standard room taken from the Oculus Home Suite). Upon experiencing the 7-min VR experience, participants were asked to engage in a personally engaging behavior, that is, donating to an environmental cause, and a socially engaging behavior, that is, taking a number of flyers to share and sign a petition. No significant differences were found between the conditions in cumulative socially engaging behavior. Still, participants exposed to the awe-inspiring virtual nature took significantly more flyers than the nonnatural awe-inspiring scenario.

In a recent investigation, Breves and Schramm (2021) examined the potential of virtual reality (VR) to bridge psychological gaps using all-encompassing 360-degree videos. They aimed to amplify personal relevance, risk perceptions, and behavioral intentions regarding environmental issues. Recognizing that 360-degree videos enhance spatial presence, amplifying the persuasiveness, credibility, and emotional resonance of media messages while simultaneously reducing cognitive resistance, the study enrolled 112 participants from Germany. These participants were divided

into one of four experimental conditions: immersive experiences through a head-mounted display (HMD) or a standard computer screen and different construal levels. The construal levels pertained to participants viewing nature scenes in either Germany (low construal due to proximity) or New Zealand (high construal due to distance). After viewing a nature video that highlighted the adverse environmental impact of mono-cropping in agriculture, particularly on bees and other insects, participants were surveyed on their perception of personal relevance, perceived risk severity, and behavioral intentions. This assessment was conducted immediately after viewing the video and again 10 days later. The study's findings revealed that participants reported a higher sense of presence in the HMD condition compared to the video condition. However, this heightened presence did not significantly influence the environmental issue's perceived spatial, temporal, or hypothetical distance. Interestingly, temporal distance was perceived as notably lower in the HMD condition compared to the video condition. Notably, increased spatial presence significantly impacted the environmental problem's perceived severity.

Walewijns et al. (2023) delved into the potential prosocial impacts of VR technology in fostering donation behavior toward an environmental organization, Water. In this investigation, the researchers explored whether utilizing an emotion-evoking 360-degree video within a VR environment could yield greater donation rates than a 2D-360 condition and a fixed-frame condition (serving as the control). In the study, participants were exposed to a 9-min factual narrative centered around water scarcity and access to clean Water. During the study, participants exhibited a stronger sense of spatial presence in the VR condition compared to the 2D-360 condition. Similarly, those in the 2D-360 condition experienced a greater sense of spatial presence than participants in the control group. Additionally, participants in the VR condition demonstrated notably higher empathy levels than the control group, although not when compared to the fixed-frame condition. The heightened spatial presence and increased empathy experienced by participants within the VR condition led to significantly heightened intentions to donate, although not necessarily translating into higher actual donation amounts. This observation underscores the presence of an attitudes–behavior gap in the context of donations.

In 2021, Oh et al. conducted a study investigating the potential of VR to encourage participants to become more involved in environmental matters effectively. In this research, 119 participants were randomly divided into two distinct conditions: the 360-degree VR condition and the unidirectional condition (serving as the control group). Contrary to the initially hypothesized outcomes, the study's findings diverged. It was observed that the utilization of VR led to a lower level of fear arousal and an increased sense of contentment compared to merely watching unidirectional videos. Strikingly, this decrease in fear and elevation in contentment corresponded with a reduced level of engagement concerning the issue of global warming. The researchers postulate that this heightened sense of contentment among participants stemmed from the greater spatial presence and improved visual aesthetics that they reported within the VR condition.

Learning, Virtual Reality, and Proenvironmental Behavior

Through a comprehensive study consisting of four components, involving two laboratory experiments and two field studies, Markowitz et al. (2018) delved into the effectiveness of virtual reality (VR) as an educational medium for providing knowledge about the repercussions of climate change in connection with ocean acidification. In the initial phase of their investigation, students assumed the role of a coral avatar, thereby encountering the consequences of ocean acidification on various species, including their own avatars. The findings revealed an enhancement in understanding the subject matter following their participation. A similar experiment was conducted in the study's second phase, where participants were divided into two groups: one embodying a coral and the other a scuba diver. Between the pretest and posttest, both groups demonstrated substantial knowledge improvement, indicating that the embodiment of these two different avatars in VR did not impact knowledge gain. The third and fourth experiments focused on motion within the VR environment, encompassing 43 college students categorized into two motion conditions: controlling their motion using a remote or moving their actual bodies. The results indicated that the type of motion employed did not affect knowledge gain. However, subsequent analyses revealed a correlation between knowledge gain, the total number of virtual snails present, and the distance covered underwater. This implies that active visual and physical engagement and exploration within the VR environment led to more pronounced knowledge gain.

In a separate investigation, Petersen et al. (2020) examined the impact of two distinct instructional setups involving 102 students in seventh and eighth grades. These students were randomly assigned to either (i) a group that received pretraining through narration followed by VR exploration or (ii) a group that encountered the same narrated instructional material integrated into the VR exploration. The students participated in a VR field trip to Greenland, engaging with a 360-degree, non-interactive VR video illustrating the melting of an ice sheet. Subsequently, they collaborated in teams to devise an experiment examining climate change's causes. They presented their findings to a hypothetical UN climate change panel. Both instructional conditions resulted in higher declarative knowledge, self-efficacy, interest, intentions related to STEM (Science, Technology, Engineering, and Mathematics), and climate adaptation-related behavioral change outcomes. However, a noteworthy distinction was observed between the two conditions. Students in the pretraining group outperformed their counterparts on a transfer test that evaluated their oral presentation to an imaginary UN panel. This underscores the idea that educators might opt to deliver essential foundational content before a VR field trip. Nonetheless, including pretraining could reduce cognitive load, potentially enhancing performance on transfer tests.

Stenberdt and Makransky (2023) explored the feasibility of a VR educational session to improve waste management in the classroom as part of high school students' formal education. In the activity, 173 students were assigned to one of four conditions to study how specific instructional design elements such as instruction sequence (direct instruction vs. productive failure) and feedback (corrective

vs. exaggerated feedback) could increase students' knowledge, intentions, self-efficacy, and response efficacy. The results show no differences across the four instructional design conditions for waste sorting; all effectively increased students' knowledge, intentions, self-efficacy, and response efficacy. Moreover, self-efficacy predicted intentions to act proenvironmentally.

Liu et al. (2019) studied the role of VR environmental education on environmental literacy and ethics. In the study, 360 participants participated in a 32-week experiment in an environmental action experience in VR. VR was used in this study as a tool for diversifying teaching forms. During these experiences, participants could practice environmental skills and explore different locations and environmental issues they were interested in. This VR experience promoted environmental ethics and skills and effectively taught students about environmental problems while querying them for possible solutions and illustrated the effectiveness of VR in complementing traditional classroom education.

In a separate investigation, Hsu et al. (2018) employed a virtual reality (VR) setting to design immersive encounters that offer individuals impactful and personally relevant information with a sense of immediacy. The aim was to enhance intentions toward water conservation behaviors. Using VR to produce immediate negative consequences of increased water consumption, bridging the perceptual gap between action and consequence of various environmental actions, 165 high school students were recruited, and water conservation behavior intentions were measured before the VR experience and 1 month after. They found that vivid and personally relevant experiences delivered in VR increased engagement with water conservation and understanding of water consumption. Moreover, behavioral feedback on the otherwise distant adverse effects of excess water consumption had higher levels of intentions to conserve water and evoked greater negative emotions about excess water use.

A recent investigation by Plechatá et al. (2022a) also delved into the enhancement of environmental self-efficacy through VR interventions to foster more environmentally conscious food choices. By utilizing virtual reality, this study aimed to enhance environmental literacy by enabling individuals to directly experience plausible scenarios of climate change and its potential impact on proenvironmental intentions, knowledge, and application. This research randomly assigned a cohort of 90 middle school students to two distinct VR scenarios. In one condition, they encountered the repercussions of their dietary choices on future environmental changes (awareness-only). In the other condition, participants experienced the effects of their food choices on future environmental shifts, with the option of altering their choices to observe a positive impact on future environmental conditions (awareness and efficacy). The outcomes demonstrated that both VR interventions significantly increased proenvironmental intentions. Moreover, self-efficacy within the awareness and efficacy condition influenced the relationship between intention and transfer. Notably, the awareness and efficacy condition yielded significantly greater enhancements than the awareness-only condition.

In another investigation conducted by Plechatá et al. (2022b), an efficacy-centered VR intervention was designed using instructional design principles to

influence eating behaviors. Within this study, 123 participants were divided into two separate conditions. In one condition, participants could engage with the environmental consequences of their dietary choices and modify their future outcomes by adjusting their food selections in IVE. The other condition served as a passive control wherein individuals could not engage with the environmental consequences of their choices nor modify their outcomes. The participants' progress was evaluated over a week preceding the intervention and a week following it. The findings indicated that the VR intervention led to a more significant reduction in individual dietary footprints than the control condition. Additionally, the intervention bolstered response efficacy and knowledge, albeit without a discernible impact on intentions, self-efficacy, or psychological distance. It is worth noting that only the knowledge enhancements endured a week after the intervention.

Smit et al. (2021) conducted a study to explore the feasibility of utilizing virtual reality (VR) to encourage environmentally conscious food consumption. In this research, 22 children aged 6–13 were engaged in a VR scenario simulating an immersive supermarket environment. During this experience, informational pop-ups emerged, providing insights into various food products' health and environmental implications. Subsequently, the participants were interviewed by the researchers regarding their encounter. The interview findings revealed that only children aged ten and above could recollect the information they encountered. Once they comprehended the information, these participants expressed awareness of and regret for the negative environmental impact of their behavior. Moreover, they stated that the experience had the potential to alter their behavior positively.

Queiroz et al. (2022) conducted two studies on the differential effects of educational IVR versus traditional videos on conceptual knowledge and self-efficacy as they relate to climate change. The videos shown to participants were *The Crystal Reef*, which focuses on ocean acidification and how carbon dioxide from human emissions negatively impacts the ocean, and *Coral Compass,* which depicts how human activities have impacted coral reefs in Palau, a small island in the Western Pacific. The first study found significant effects of VR and self-efficacy. In the second study, participants in IVR had higher scores for knowledge creation but not knowledge understanding or knowledge application compared to the desktop group. While the IVR group scored higher on self-efficacy than the desktop group in Study 1, this result was not found in Study 2. Moreover, learning agency was found to mediate the relationship between conditions and self-efficacy in study 2, indicating a possible mechanism underlying immersion effects on self-efficacy.

Queiroz et al. (2023) investigated how the design of a virtual reality (VR) experience addressing ocean acidification influenced the learning, behavior, and perceptions of climate change among 305 participants. They manipulated various factors, including message framing, voice-over gender, experimental pacing, and participants' body movement, across 17 locations spanning four countries. The study randomly assigned participants to one of 16 conditions within the Stanford Ocean Acidification Experience, in which participants can embody a scientist and experience the effects of climate change on ocean biodiversity. These conditions involved combinations of variables such as movement (seated vs. standing), segmentation (pauses of either 3 s or 20 s, during which participants reflected on the

preceding content as the screen turned black), framing (climate change vs. ocean acidification frame), and narration (female vs. male narration). The findings indicated that walking during the VR experience led to heightened self-efficacy but hindered learning. The researchers attribute this to an increased number of predictions that the brain makes and a stronger sense of agency and self-efficacy when these predictions are validated. Moreover, the study demonstrated that the climate change message frame resulted in lower learning levels than the ocean acidification frame, a finding that the authors suggest was, in part, due to the politicized nature of the term "climate change," which could reduce trust and impede learning. The researchers also suggested that the phrase might evoke overwhelming feelings and anxiety, triggering defensive psychological processes that hinder effective learning. Risk perception mediated the relationship between knowledge and behavior while learning did not directly impact behavior.

Raja and Carrico (2021) also explored the use of environmental virtual reality through the lens of psychological distance with the Stanford Ocean Acidification Experience and qualitatively found that participants who were in VR felt that they were interested in doing more, in addition to learning more about the ocean.

Risk Perception, Virtual Reality, and Proenvironmental Behavior

In a recent study, van Gevelt et al. (2023) examined the impact of VR exposure to a future tropical cyclone simulation intensified by climate change on risk perceptions and individual efforts toward mitigation. This investigation involved a representative group of 1507 participants from Hong Kong. The study's results indicated that encountering the simulation was linked to a slight decrease in risk perceptions and individual mitigation behavior. This outcome was attributed to increased skepticism toward climate change, a sense of helplessness triggered by the simulation, and concerns related to the virtual experience, including realism and the absence of a first-person perspective.

In 2022, Mol et al. explored the utilization of VR to ascertain whether a simulated disaster could motivate individuals to undertake risk-reducing actions in the context of flooding. The study also aimed to assess the durability of these effects by conducting a follow-up survey 4 weeks after the VR intervention. During the activity, participants were placed within a neutral home setting and instructed to navigate through the room. Following this initial phase, participants found themselves in their backyard and were tasked with stacking sixteen sandbags in front of a window. Upon completion, they received a message indicating their home was "Protected." Subsequently, participants observed water outside their window, with various garbage bins floating down the street. The experience then transitioned to witnessing a flood in an unprotected neighboring residence. This residence experienced a power outage due to the flood, and participants were prompted to use a flashlight to assess water levels and floating objects. Following the VR intervention, participants engaged in a flood risk investment game that allowed them to make investments for flood-related measures. After completing the game, participants were required to fill out a survey. The study's findings revealed that, compared to

participants in the control group (who solely participated in the flood risk investment game), those in the VR group were notably more inclined to invest in the flood risk investment game immediately after the VR experience. However, these effects appeared to diminish over time, as no significant differences were observed after the 4-week follow-up period.

Information Provision, Virtual Reality, and Proenvironmental Behavior

Chirico et al. (2021) studied the effects of different statistical information formats in VR for plastic consumption, recycling, and waste. Within the study, a cohort of 172 students was exposed to one of three formats for statistical information: numerical, concrete, or a combination of both. Following the VR experience, participants completed a survey gauging their emotions, affect, sense of presence, general environmental attitudes, and specific attitudes and intentions regarding plastic usage, waste, and recycling. The findings indicated that presenting solely numerical data in an IVE could have been more effective than the concrete and mixed formats. The latter two formats yielded similar effects in terms of presence due to the immersive quality of the simulated setting. Notably, the mixed format led to higher general environmental attitudes, environment-related affective attitudes toward plastic waste and usage, and greater acquisition of information about environmental concerns compared to the numerical format. Moreover, the concrete statistical information evoked stronger emotions of fear, disgust, sadness, and awe than the abstract numerical format. These results underscore the persuasive potential of providing concrete information within the VR context to foster proenvironmental attitudes and encourage behavior intentions against plastic consumption and.

In Meijers et al. (2022), participants engaged with interactive displays featuring impact messages linked to products they encountered within virtual reality (VR) supermarkets. This study, involving 249 participants, aimed to determine whether these messages could effectively trigger personal response efficacy beliefs and the duration for which these beliefs persisted following the VR encounter. The research employed a randomized assignment of participants to different types of impact message appeals (health vs. environment) and varied levels of vividness (low: text only vs. high: text and visual) for the impact messages. The study assessed changes in behavior through the lens of personal response efficacy beliefs at three different time points. During the initial stage, participants were presented with four products, each with varying degrees of adverse environmental or health impacts. Following the simulation, participants were asked about their purchasing decisions for the past week, and this assessment was repeated 2 weeks after the VR experience. The study revealed that inducing personal response efficacy beliefs within the VR setting resulted in subsequent increases in proenvironmental food selections. This trend persisted for up to 2 weeks following the VR encounter.

Another recent study by Ball (2023) explores how VR experiences can provide an avenue to make nature tourism more environment friendly while increasing

environmental connection and consciousness through spatial presence and narrative persuasion. In the activity, 66 college student participants were randomly assigned to two conditions: (1) VR travel, wherein participants experienced several short underwater experiences with whales, and (2) TV control, wherein participants watched a video about whales. No statistically significant differences were found between VR travel and TV control conditions on oceanic attitudes and activism intentions. However, spatial presence and narrative engagement mediated support for attitudes and activism intentions in the VR travel condition.

Kleinlogel et al. (2023) investigated how being immersed in VR during a promotional campaign could promote higher proenvironmental attitudes and behavioral strategies compared to traditional 2D television media and print media due to the user's ability to be present in the medium and seeing the effect that their energy-savings behavior. To do so, they tested the differences between perceived norms, attitudes, and behavioral strategies to save energy at home through traditional, print, or video message campaigns, or in an IVR-based campaign where the message was either delivered by a doppelganger or an unknown virtual agent. However, no effect was found as it relates to perceived individual norms on energy savings. Moreover, interacting with a doppelganger virtual agent, one that looks identical to the user, had no significant effects compared to interacting with an unknown virtual human in the IVR condition.

Oh et al. (2020) compared the persuasive effectiveness of proenvironmental 360-degree videos to unidirectional videos. Among other findings, they found that participants who had greater perceived interactivity in the 360-degree videos had higher promotion intentions, in that they were more willing to add new environment-friendly behaviors to their lives, but not reduce their current resource consumptions.

Given the focus on adopting more environmental habits and behaviors in various social science, psychological, and communication literature, it is no surprise that this has been the focus of VR studies lately. The studies presented in this section elucidate how active visual and physical engagement and exploration within VR environments can produce greater knowledge gains compared to traditional media, as well as how it can be an effective tool to diversify the content in school curricula by presenting material in different ways and increase self-efficacy, which has been seen to increase proenvironmental intentions and actions. However, researchers have noted that the medium's power to deliver powerful experiences can also trigger negative consequences, such as increased helplessness and skepticism about climate change, which may be inconducive to environmental action. As such, VR content creators and developers should pay close attention to the content they develop, its impact on user experience, and how users may interact within the experience to prevent potential negative consequences.

Virtual Reality for Policy Support

This section describes two studies investigating how different aspects of VR could promote support for proenvironmental policies. Deringer and Hanley (2021) conducted a study to investigate the connection between virtual nature encounters

and ecological behaviors. The study involved 57 participants recruited from a trailhead and a local retail store situated within an area influenced by the passage of the Colorado Outdoor Recreation and Economy (CORE) Act. This policy aimed to safeguard historically significant outdoor recreation spaces by designating them as wilderness areas, thereby protecting them from development and resource extraction (The CORE Act, US Senator Bennet). The participants were divided into three distinct conditions: (1) the nature condition, which involved a 30-min hike in a natural environment; (2) the VR condition, where participants engaged in a 10-min VR simulation of the same nature hike; and (3) the control condition, which did not involve exposure to natural settings. The participants underwent a pre- and posthike survey encompassing ecological behavior measures, including the Nature Connectedness Scale (Mayer and Frantz 2004) and the Inclusion of Nature in Self Scale (Schultz 2002). Additionally, to address the gap between environmental values and behaviors, participants were asked if they were interested in signing a letter to the senator to support the CORE Act after completing the survey. The study revealed that both the nature and the VR nature conditions yielded similar ecological behavior levels, surpassing the control condition's effectiveness. These findings underscore the potential of VR nature experiences to evoke ecological behavior in situations where direct access to natural settings is unavailable. However, it is crucial to note that the duration of exposure differed between the nature and VR nature conditions. Equally prolonged VR exposure could introduce new challenges, such as visually induced motion sickness (VIMS).

In a different vein, Calil et al. (2021) used VR for community engagement and to help decision-makers better visualize the impacts of climate change, supporting sea level rise planning. They elaborated that given the slow and temporally distant process at which sea level rise impacts people, VR's immersive, interactive, and safe learning environment would allow better communication and community engagement. This was done by VR experiences of sea level rise in three US coastal communities, namely Turner Station in Maryland, Santa Cruz in California, and Long Beach in California. Preliminary data from participants who experienced VR sea-level rise in Santa Cruz reported feeling it to be "more realistic than 2D maps on paper" and "drove the reality home." Moreover, users familiar with the locations portrayed in VR showed stronger emotional reactions than those unfamiliar with them.

Future Directions

This chapter reviewed the recent applications of virtual reality in fostering environmental citizenship. We explored the psychological barriers impeding the adoption of environmental citizenship. Subsequently, we delved into the attributes and affordances of VR that contribute to its efficacy in overcoming these barriers. The following section outlines takeaways from the reviewed studies and offers directions for future research.

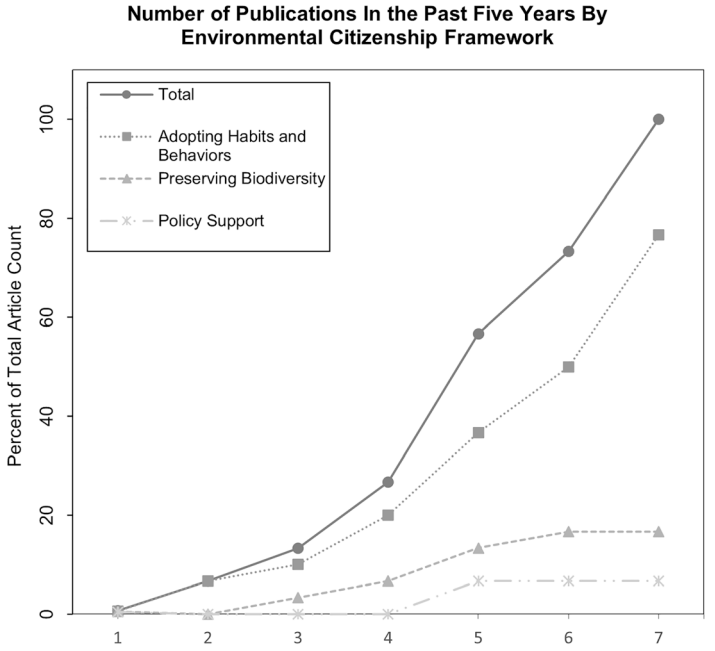

Fig. 1 Distribution of peer-reviewed journal articles categorized by VR research done in the three environmental citizenship framework components

Our review indicated that only three environmental citizenship dimensions were explored, with one of the dimensions involving only two empirical papers. While there is a need to better understand how VR and its affordances can promote environmental citizenship, this field is rapidly evolving, with more than twenty studies published in the past 5 years (Fig. 1). Upon reviewing recent studies that illustrate how VR can be a tool to promote environmental citizenship, certain limitations were found.

First, varied outcomes have been observed in both recent and historical research when investigating the significance of spatial presence and immersiveness on environmental behavior. VR's affordances for immersion, presence, and embodiment, it can be hypothesized that more immersive media like VR exert a stronger persuasive influence on environmental behavior compared to less immersive media such as traditional 2D desktop videos or articles. Conducting a meta-analysis of empirical studies concerning the effects of presence and immersiveness on environmental behavior could offer insights into these inconsistencies and yield a more accurate and precise effect estimation by consolidating various individual study findings (Rosenthal and DiMatteo 2001).

Second, only a few studies include actual behavior measurements instead of self-report measures (Bailey et al. 2015; Deringer and Hanley 2021; Plechatá et al. 2022c; Queiroz et al. 2023). This results in a focus on measuring intent, an

individual's intention to act, as opposed to impact or the real impact of their behavior. Given the existing literature on the attitudes–behavior gap, future research could involve tangible behavior measures, such as endorsing petitions and policies, contributing to environmental organizations, or monitoring water and energy usage postsimulation.

Additionally, the extensive data obtained through VR headsets, encompassing head and gaze tracking, could be leveraged to objectively assess behavioral outcomes, as self-reported responses might be influenced by social desirability (Shadiev and Li 2022; Zito et al. 2015). Other less frequently employed methodological approaches, such as field experiments, focus groups, and participatory design studies, could be integrated into research on VR, as these approaches are rarely seen in scientific publications (Queiroz et al. 2023; Aitamurto et al. 2021). Only one known study has applied participatory design in employing VR for teaching ocean acidification and climate change (Fauville et al. 2021).

In addition, most recent VR studies target low-impact environmental behaviors, such as recycling and water savings, instead of high-impact behaviors, such as household energy and water conservation, signing petitions, or policy support, which are tenets of environmental citizenship. While all individual actions could help with climate change mitigation and adaptation, the urgency of the climate crisis implores us to ask how VR technologies can help promote more high-impact behaviors to decrease GHG emissions. Our review above illustrates that only six studies target high-impact behaviors (Smit et al. 2021; Meijers et al. 2022; Plechatá et al. 2022a, b; Deringer and Hanley 2021; Queiroz et al. 2023).

Another limitation of studies includes the often passive rather than active component of experiencing climate change in VR. In the review above, less than half of the studies included participant interaction with the VR stimulus. While the understanding of what features make learning activities in VR an effective medium in promoting environmental behaviors is still in its infancy, the extant literature has indicated that one of VR's unique affordances is the ability for immersion and interaction within the medium and tap into emotions, contributing to media richness, and this should be further explored as it relates to environmental behavior adoption (Fauville et al. 2020; Markowitz and Bailenson 2021).

Furthermore, few studies thus far have investigated how user personality influences how they interact in environmental VR settings (Cosio et al. 2023). Prior research has indicated that personality traits such as introversion can influence a sense of presence in VR and how introverts perceive the environment differently from extroverts (Alsina-Jurnet and Gutierrez-Maldonado 2010; Song et al. 2021; Senese et al. 2020), future research on how VR interventions interact with dispositions and traits and how they influence environmental behavior, habits, and policies following the intervention could be valuable for research. For instance, VR interventions may be most beneficial for those with low trait abilities, such as openness, empathy, imagination, and compassion, compared to those already high in these abilities.

Notably, most research on virtual reality and climate change mitigation and adaptation was conducted in Western, educated, industrialized, rich and democratic

(WEIRD) societies, and therefore, students' educational and family backgrounds reflect such populations. Given that climate change disproportionately affects communities outside of these societies, future work could benefit from the inclusion of voices of students from communities most affected by climate change and participants from diverse backgrounds.

Another immersive technology that has the potential to become an essential tool in promoting environmental citizenship is augmented reality (AR). AR is a real-time or indirect view of a physical, real-world environment that has been enhanced or augmented by superimposing computer-generated input through a smartphone or the Microsoft HoloLens (Yang and Li 2016). While a review by Cosio et al. (2023) has illustrated that fewer empirical investigations use AR compared to VR, AR's growing availability on social networks and smartphone devices makes it easily accessible for people to experience and share with their communities as such, it could be used to change social norms, an important aspect of environmental behavior change (Constantino et al. 2022). This concept is yet to be empirically tested; however, recent work by Chen (2022) has illustrated the increased self-efficacy and environmental behavior students adopted on learning with AR digital picture books and the use of AR games for conservation outreach in improving participants' intention to donate to conservation (Dunn et al. 2021).

Notably, while some studies have illustrated that VR nature experiences may induce the same environmental behavior as interacting in physical nature, we do not advise using VR nature experiences to replace physical nature. Given that work is still ongoing in identifying the boundary conditions and longitudinal effects of VR on climate change attitudes and its effects on different populations, such as the elderly and children, VR nature should be a complementary experience to physical nature experiences.

Furthermore, careful consideration should be given to determining the appropriate scenarios where immersive VR experiences are necessary for promoting environmental behaviors. As outlined by Bailenson (2018), the adoption of immersive VR experiences should be limited to situations where the experiences are within the DICE framework, namely, dangerous (e.g., simulating the impact of a wildfire), impossible (e.g., visualizing future outcomes of current actions), counterproductive (e.g., simulating tree felling to illustrate deforestation effects), or expensive (e.g., simulating global travel) (Bailenson 2018). For instance, examining emotions triggered by nature exposure and its influence on conservation attitudes may not necessitate immersive VR experiences. Yet, exploring conservation attitudes through a virtual nature excursion amidst extinct species and its subsequent impact on feelings of awe within a VR environment could provide insights into potential support for future conservation policies. While encountering and gauging the effects of awe in the physical world among extinct species would be impossible, immersive VR can amplify individuals' belief of anthropogenic climate change's impact on such species and intensify their commitment to support conservation policies. Moreover, given that most research to date focuses only on evaluating the efficacy of virtual reality experiences compared to other media or its efficacy in education, VR alone is not enough to promote environmental citizenship, and the design of an

experience is more important than immersion alone to have positive effects in environmental citizenship factors.

Conclusions

Climate change is an immediate and urgent problem that affects individuals, communities, and societies. Personal experience has been lauded as a powerful teacher in promoting environmental behaviors for citizenship (Ballew et al. 2019). VR provides a tool for individuals to experience climate change, even when they are not proximally located in areas already facing its effects. Revisiting the question presented in our title, "Can Virtual Reality Experiences Promote Environmental Citizenship for Climate Mitigation and Adaptation?", at least two responses exist. First, it is important to acknowledge that VR's effectiveness in promoting environmental citizenship hinges on collaborations with other disciplines encompassing the physical, psychological, and social sciences to provide accurate psychological understandings of climate change and methodological considerations. Second, we must recognize that tackling issues as imminent as climate change requires incorporating technologies like virtual reality for collective success. While VR education programs for climate change mitigation and adaptation that account for interdisciplinary fields are limited at the present time, faculty and administrators that aim to develop an educational program would benefit from understanding the fundamental principles of learning in VR. These principles include the deliberate planning of course-relevant VR experiences such as those that align with the DICE framework mentioned above, preparing for technical issues that arise from VR content and platforms, accounting for the types of social interactions and time spent in VR as part of the course and an overall understanding of how VR complements courses and learning goals (Han and Bailenson 2024).

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