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Exploring the Potential of Virtual Reality as a Tool for Enhancing Climate Change Awareness: A Review

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1 Abstract

Climate change is one of the biggest social, cultural, environmental and economic issue we face in modern society which takes solutions from everyone at every level. Regular climate education rarely meets the complexity and fear of climate change with its trauma-informed methods. Researchers have explored the use of Virtual Reality (VR) as a tool to enhance climate change literacy. VR is an asset allowing us to visualize realistic situations and under-stand what happens in climate change, reinforcing our emotional response. It also gives them a better insight into distant environmental issues. Based on an analysis of several studies, VR is examined as a possible educational resource to increase climate change literacy. Being that VR platforms can be anything from high-end headsets to low-cost devices, their availability empowers educators with the ability to target a broad audience. The only way one gets an interface to be both meaningful and enjoyable, is by improving renderings, controls responsiveness, and user experience. Until the expansion and subtle integration of VR into education systems, VR might be the best tool we have to raise environmental awareness and inspire sustainable actions for future generations.

2 INTRODUCTION

The reality of climate change has emerged as one of the largest global issues of the 21st century, having vast social and environmental impact and economic effects. There is broad scientific agreement about the drivers and impacts of climate change [1]. The way climate change impacts people complex, abstract and often too distant in time and space for them to appreciate is part of what makes it so challenging to move people to action. Climate education is often presented in static

forms that fail to elicit a strong emotional response or sense of urgency such as reports in paper and video formats [2]. It has prompted scientists to find new and better ways of communicating climate change risks, as well as engaging pro-environmental behaviors. Virtual Reality (VR) has come to the fore as a promising approach in this regard. VR can empower Users to experience the impact of climate change directly through immersion and interaction allowing them to understanding by doing [3]. Virtual reality (VR) has the ability to radically change how people think about and respond to climate change, from simulating rising sea levels, to immersing users into hypothetical future climates. VR has the power to change how we think about and respond to climate change, from simulating melting ice caps, to putting users in both sides of the future impacts of rising sea levels [4]. The University of Maryland study also assessed learning in a virtual environment, where participants were required to learn and recognize faces through both real-world and virtual actions. In all three cases 2D images, VR photos, and VR subjects there was a substantial increase in facial memory. An increased awareness of space aided 70% of the users in succeeding [5]. VR provides a felt immediacy that traditional media often cannot, allowing for the creation of emotional connections and empathy between distant gradual environmental processes and individual humans who experience these phenomena [6].

This review aims to explore the potential of VR as an educational tool for enhancing climate change awareness. By analyzing various VR applications across different studies, we evaluate the effectiveness of VR in fostering environmental concern, influencing attitudes, and promoting behavioral change. Furthermore, this paper examines the technological aspects of VR implementations, including the platforms, hardware, and user feedback, to understand the role that technology plays in the success of VR interventions. In conducting this review, a number of academic databases, such as Google Scholar, Web of Science, and IEEE Xplore, were searched with appropriate keywords including “VR in climate awareness” and “VR uses in climate change education.” Studies conducted in last decade has been selected for the review. These sources were selected to gather a wide range of peer-reviewed studies focused on the intersection of VR and climate change.

This paper contributes to the growing body of research by offering a comprehensive review of VR’s role in climate change education, which has not been fully explored in previous studies. While prior research highlights the educational benefits of VR, no existing review systematically compares the different studies or details the specific VR hardware and its ease of use. By addressing these gaps, this paper not only synthesizes the findings from various studies but also provides insights into how the choice of VR technology and user experience influences the effectiveness of VR. Through this detailed review, we aim to support future research and the development of more impactful VR-based educational tools.

3. Literature Review

For the purpose of creating environmental mindsets and increasing knowledge of climate change, the research con-ducted by [7] investigates the impact of immersive VR. The authors conducted an experimental study using three different VR conditions; abstract, realistic, and highly realistic depictions of glacier melting and compared them to a control group. The findings indicate that immersive VR, regardless of the level of visual realism, significantly in-creased environmental awareness among participants, as measured by the New Ecological Paradigm (NEP). The study also showed that realism in VR does not necessarily correlate with stronger presence or improved attitudes toward climate change. In fact, even an abstract environment, if coherent and authentic, can have the same positive impact on environmental awareness as highly realistic environments. However, the study highlights the importance of further research, particularly in exploring the relationship between VR design choices and pro-environmental behavior. It also calls for the use of more implicit measures, such as the Implicit Association Test (IAT), to evaluate the long-term impact of VR on behavior. While

VR can effectively visualize the consequences of climate change, broader societal and institutional changes are necessary to address the issue comprehensively.

Another study by [8] examines the effectiveness of integrating Problem Based Learning (PBL) with climate change VR videos through mobile applications to improve critical thinking skills among high school students. The findings reveal that this PBL approach, combined with VR content, significantly enhances students' critical thinking abilities, outperforming traditional teaching methods. The authors observed a notable improvement in the treatment group's critical thinking skills between the pre-test and post-test, with the control group also showing some progress. Additionally, the analysis of variance (ANOVA) confirmed significant differences in critical thinking scores across both intervention groups, and post hoc comparisons further validated the effectiveness of the learning strategy.

Queiroz et al. [9] examined how VR has become a powerful tool for immersive education, particularly in environ-mental sciences. A recent study explored how the design of a VR experience about ocean acidification could affect participants' learning and climate change behaviors. The study manipulated various elements, including body movement, message framing, and narration style, and found that increased physical movement heightened participants' self-efficacy but surprisingly hindered learning. Moreover, linking ocean acidification explicitly to climate change impaired knowledge retention. These findings suggest that while VR is effective for engagement, careful design is crucial to optimize learning outcomes and promote pro-environmental behaviors.

Dhunnoo et al. [10] explores the application of VR for urban modeling and spatial data visualization, highlighting its potential to enhance user interaction with complex urban environments. By leveraging immersive VR technology, users were able to engage with 3D urban models in a more intuitive and comprehensive manner, facilitating improved spatial understanding. The study evaluates the effectiveness of VR for urban planning and public engagement, receiving generally positive feedback from users, though it notes some challenges related to hardware limitations and interface design. The study concludes that VR offers significant advantages for visualizing urban data, particularly in enhancing the ease of interpretation and decision-making processes.

The authors in [11] provides a comprehensive review of how VR has been utilized to understand and influence attitudes and behaviors concerning climate change. The study discusses how VR has emerged as a powerful medium for climate change education and how it allows users to experience environmental issues in an immersive way, which helps deepen their understanding and emotional connection to complex topics like ocean acidification and energy use. The authors also highlight how VR can bring climate change science closer to participants, making them feel more engaged and emotionally affected by environmental devastation. The use of VR for simulating future climate scenarios or putting users in the perspective of different entities (like corals or animals) helps foster greater concern and understanding of the issues. The study shows that virtual reality's key affordances—presence, immersion, and embodiment—are essential for creating meaningful experiences. These elements contribute to making users feel as though they are "there" in the virtual environment, which has been shown to enhance learning and engagement in environmental topics. The review mentions specific VR applications that have been used to study and teach climate change, such as the Stanford Ocean Acidification Experience and virtual simulations of energy use impacts. These

immersive experiences help users witness the consequences of environmental issues firsthand.

Posluszny et al. [12] explores the application of VR in enhancing sustainability education, particularly regarding climate change. Employing a user-centered design approach, the researchers developed a VR prototype simulating flooding scenarios in Miami, designed to foster empathy and inspire behavioral changes among college students. The study involved participatory design methods, including semi-structured interviews, focus groups, and story-boarding, to ensure that the final VR experience resonated with users' perspectives. The findings demonstrated VR's effectiveness in cultivating emotional connections to climate change issues, though participants also experienced desensitization from repeated exposure to distressing imagery. To counter this, the VR experience concluded on an uplifting note, encouraging actionable responses for climate change mitigation. Overall, the study underscores the potential of VR as a transformative educational tool that can be adapted across various cultural contexts to enhence global climate change awareness and action.

The study in [13] investigates the effectiveness of virtual reality news in enhancing climate change learning by comparing it with 360° video and Text-With-Images (TWI) formats. While the findings reveal no direct impact of VR on learning outcomes, they highlight indirect effects on cognitive elaboration, influenced by participants' preexisting knowledge of climate change. The primary objective was to assess the learning effects of immersive VR news and explore its potential as an educational tool for climate science within multimedia environments. The researchers conducted a controlled, in-person laboratory experiment using a pre/posttest design with three conditions: VR, 360° video, and TWI. Participants were randomly assigned to these conditions, with the experiment employing a double-blind procedure. Learning outcomes—such as cued recall, free recall, and cognitive elaboration—were measured alongside mediators like presence, flow, and cognitive absorption. The results indicate that immersive VR does not directly improve learning from news content, and simplifying content alone may not enhance learning outcomes. However, minimizing extraneous information proved beneficial, suggesting that design efforts should focus on content reduction. Additionally, the study identifies an indirect effect of VR on learning through cognitive pathways, with deeper learning achieved when VR content is thoughtfully designed.

The study [14] examines the use of a high-fidelity VR prototype, Melbourne 2100, to engage participants with cli-mate change and promote civic action. The findings highlight the potential of VR as an effective medium for raising public awareness about climate issues and fostering climate engagement. After experiencing the simulated future scenario of a flooded Central Business District (CBD) in Melbourne, participants reported a slight increase in their perceived vulnerability to climate change. Moreover, all participants acknowledged the city's vulnerability to the impacts of climate change. The study employed a Research Through Design approach, aiming to develop and test the effectiveness of the Melbourne 2100 VR application. A mixed-methods framework was utilized, incorporating both quantitative and qualitative data collection through observation, interaction logging, semi-structured inter-views, and questionnaires. Participants took part in interviews and surveys to provide feedback. The results indicate that the immersive experience not only heightened participants' awareness of climate risks but also encouraged them to engage in civic activities, such as voting in favor of climate policies.

These findings suggest that VR can be a powerful tool in mobilizing public support for climate action, providing an engaging way to communicate the real-world implications of climate change. Furthermore, Table 1 summarize the existing study's methodologies and their findings.

Table 1. Summary of existing studies and their findings

Study	Focus of study	VR Application	Methodology	Findings
[7]	Impact of VR realism on environmental awareness	Glacier Melting Simulation (Abstract, Realistic)	Mixed-effects model, VR vs. non-VR	VR regardless of realism, significantly increases climate awareness
[8]	Effectiveness of PBL integrated with climate change VR videos	VR videos from UN Environment Program	Pre/post-test design; ANOVA for comparing groups.	Significant improvement in critical thinking skills in the treatment group.
[9]	VR as a tool for climate change education and behavior change	Ocean Acidification Simulation	Immersive experimental design	Increased emotional engagement and understanding of environmental risks
[10]	Use of IVR to improve urban planning	Inundated urban landscape	Immersive experimental design	IVR enhance understanding of climate change impacts.
[11]	VR experiences can influence participants' learning related to ocean acidification	Stanford Ocean Acidification Experience	Immersive experimental design	VR interventions can effectively foster environmental awareness.
[12]	Design a VR educational experience	Flood in Miami	Immersive experimental design	Effectively foster empathy, deepen understanding, and inspire climate action.
[13]	Effectiveness of VR news for learning about climate change	VR news story in 360 and TWI, featured on CNN news	Controlled, in-person lab experiments	VR does not directly impact learning outcomes but affects cognitive elaboration

[14]	Use of high-fidelity VR prototype, Melbourne 2100, to engage the public and encourage civic action	Melbourne 2100 VR experience simulating a flooded CBD	Research Through Design method	Participants' perceived vulnerability to climate change increased slightly and willingness to engage in civic activities.

4. Technological Implementations of VR in Climate Change Awareness

Virtual reality uses computer technology to generate an immersive simulated environment. It can be used to recreate real-world locations and facilities, objects, equipment and even people. According to Amaury La Burthe, CEO and Creative Director of Nove lab, "VR increases the rate of memorization because it allows the brain to create associations between the subject and the environment in which they are located. The way that VR engages the body promotes the retention of information and the involvement of the user in the experience" [15]. The use of this technology goes beyond its leisure and commercial properties. Indeed, VR can be used for social, environmental, as well as educational purposes. In a global context, both virtual reality and augmented reality have been put at the service of the environment. As virtual reality gains importance and its applications extend across various domains of life, its usability becomes increasingly crucial. One can experience virtual reality through VR glasses, commonly known as Head-Mounted Displays (HMDs) or headsets. A well-designed VR headset plays a crucial role in delivering an immersive, comfortable, and safe virtual reality experience [16]. In contrast, low-quality headsets can lead to physical discomfort, such as eye strain and cyber sickness, resulting in user frustration. The resolution of the headset significantly impacts the clarity and sharpness of the visuals, with higher resolutions minimizing the screen door effect (visible pixel lines) and enhancing the overall visual experience. Given that users may wear headsets for extended periods, comfort is essential. Features such as adjustable straps, balanced weight distribution, and soft padding around the eyes and face ensure a better fit and prevent discomfort. Additionally, accurate motion tracking is another important aspect, as it ensures smooth and precise translation of the user's movements into the virtual environment, enhancing interactivity and immersion. A combination of these factors contributes to an enjoyable and effective VR experience.

The existing studies used a range of headsets, from high-end immersive VR HMD, such as the HTC Vive and Oculus, to more accessible mobile VR options like smartphones. For example, Markowitz & Bailenson [11] utilized an immersive VR platform on the HTC Vive to simulate ocean acidification, which was highly effective in fostering an emotional connection to climate issues. Similarly, the study [14] employed a high-fidelity VR prototype on the Oculus Quest, receiving positive feedback on ease of use and engagement. On the other hand, mobile VR was used in a PBL scenario [8], which, while moderately easy to use, proved effective in

enhancing students' critical thinking. Interestingly, while some studies like the CNNVR app using the Oculus Rift did not mentioned the ease of use, the immersive VR technology in [7] was praised for its graphical appeal and ease of use, further supporting VR's potential in climate education.

This variety in platforms and feedback emphasizes the flexibility of VR technology in climate education, catering to both high-fidelity experiences and more accessible mobile solutions, while still achieving impactful educational outcomes. The Table 2 focuses on the technological details of the VR platforms and prototypes used in each study could provide additional depth.

Table 2. Usability Analysis of VR headsets

Study	VR Platform	Hardware	Ease of Use	User Feedback
[7]	Three VR environments for glacier melting	HTC Vive, HTC Vive Pro	High	The VR experience was graphically pleasing.
[8]	PBL with Climate Change VR	Smartphone	Moderate	Effective in enhancing critical thinking
[9]	Recreate a flood-affected urban environment	iPad Pro's LiDAR Scanner	High	VR provided a more engaging and understandable way to interpret spatial data compared to traditional methods
[10]	Stanford Ocean Acidification Experience	VR headsets and controllers	Moderate	Positive in terms of self-efficacy
[11]	Ocean Acidification VR	HTC Vive	High	Deepened emotional connection
[12]	Simulating flooding in Miami	Not specify	High	VR experience effectively built empathy and emotional responses regarding climate change
[13]	CNNVR App	Oculus Rift Gaming desktop	Not mentioned	Not mentioned

[14]	Melbourne 2100	Oculus Quest	High	Positive feedback on ease of use and engagement

5. Conclusions

This study highlights the potential of VR as an innovative tool for enhancing climate change awareness, fostering environmental concern, and promoting pro-environmental behavior. The studies demonstrate that VR's immersive and interactive nature can evoke emotional engagement, bridge the gap between abstract environmental issues and personal experience, and inspire behavioral changes. However, the effectiveness of VR is influenced by several fac-tors, including design elements, the level of realism, and the structure of educational interventions. The findings em-phasize that VR experiences, whether simulating ocean acidification, rising sea levels, or future urban flooding can effectively enhance understanding and engagement. The success of these interventions depends not solely on visual realism but also on coherence, narrative framing, and user interaction. Additionally, problem-based learning ap-proaches and participatory design can further enhance the impact of VR-based education by fostering critical thinking and personal connection. Despite VR's promise, challenges remain. Some studies point to hardware limita-tions, user desensitization, and the need for simplified content to maximize learning outcomes. Furthermore, while VR can raise awareness and influence attitudes, lasting behavioral change requires integration with broader societal initiatives. Nonetheless, VR offers a powerful complement to traditional climate education methods, enabling users to experience the consequences of climate change. Future research should focus on refining VR designs, exploring long-term behavioral impacts, and integrating VR tools with institutional efforts to address climate change compre-hensively. By leveraging VR effectively, researchers, developers, educators and social activists can foster deeper public engagement, ultimately encouraging meaningful actions toward environmental sustainability

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