Original Contribution

Exploring Immersive Mixed Reality Simulations and Its Impact on Climate Change Awareness

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Purpose: To combat widespread climate change misconceptions that halt mitigation efforts, we investigate Mixed Reality's applicability in helping contextualize climate change consequences.

Design/methodology/approach: We propose an immersive Mixed Reality system that simulates personally-relevant experiences relating to climate change disasters. To evaluate our methods, we conducted a pilot study with the constructed Mixed Reality system and analyzed collected statistics.

Findings: Participants reported heightened motivation to adopt more sustainable practices as a result of Mixed Reality system use; collected statistics display increased levels of stress and ratings of immersion from system use. Results display prominent applicability of Mixed Reality systems in climate change contextualization.

Research limitations/implications: Due to the lack of accessible Head-Mounted Displays, the pilot study is confined to a Mixed Reality format. Future work can examine effects of more realistic and localized approaches on stress and inclination levels; these effects may include real-time scanning and geographical mapping, dynamic object placement, information prompting, and improved spatialized audio.

Originality/value: We evaluate the relative effectiveness of current communication mediums and propose a novel MR system as a solution to global mitigation challenges. We evaluate the effectiveness of conveying climate change awareness topics through Mixed Reality with a pilot study.

INTRODUCTION

Global climate change is the notion that increased levels of carbon dioxide contribute to changes in global climate patterns. Although it serves as one of the largest threats to modern society, climate change remains an afterthought in public policy, manufacturing, and individual lifestyles. Understanding and targeting human psychology is crucial in minimizing climate change misconceptions and bringing climate change to the forefront of global discussions (Clayton et al., 2015). Individuals with the common belief that natural variation is the primary cause of climate change tend to believe that there is nothing humans can do to slow or stop the effects of global warming (Fleming et al., 2021). Individuals with the common belief that natural variation is the primary cause of climate change tend to believe that humans can contribute little to slow or halt the effects of global warming. These beliefs create an acquiescent society that enables climate change to heighten at an exponential rate.

Mixed Reality (MR) is the convergence of the physical and virtual worlds, related to the terms Virtual Reality (VR), and Augmented Reality (AR). VR defines applications taking place fully in virtual and simulated environments, while AR defines applications taking place in the physical world with digital elements communicated through visual overlays. These applications are typically rendered and delivered through Head-Mounted Displays (HMDs), which are

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head-mounted devices that provide visual immersion by projecting simulated images. MR applications have been recognized for their ability to provide immersive and visually transformative experiences, proving to offer practical solutions in fields such as military training, entertainment, and design.

MR applications have shown expanding technological prominence in modern software (Mandapuram & Hosen, 2018). Its increase in popularity is reflected in the continued development of commercially-accessible HMDs, with the Oculus Rift, Valve Index, and HTC Vive being the devices of greatest commercial demand. MR applications used for industrial design and enterprise applications are typically designed for HMDs that target industrial purposes, such as the HoloLens 2 manufactured by Microsoft.

Established methods of increasing climate awareness include television, newspapers, magazines, and the internet (Pandve et al., 2011). Despite their widespread use, existing methods have yet to achieve remarkable immersion and interactivity. In climate change discussion, visualizations allow users to see the consequences rather than statically hear about them. One prominent form of immersive visualizations is Mixed Reality, which provides a format for individuals to immerse themselves in a nontraditional and *experiential* way that allows them to experience new systems rather than simply reading or hearing about them (Cho et al., 2007).

Focusing on regional climate change outcomes that pertain to students living near the Kirby Crossing location at the University of California, Santa Barbara, we constructed a Mixed Reality experience to evaluate the role MR plays in promoting climate change awareness. Recent fire seasons and historical fire trends reflect significant human-caused warming and project the continued increase of wildfire activity within California regions. Displayed centennial warming trends in the past decades align with simulated anthropogenic trends from climate models, indicating the increasing relevance of wildfires in the future of Kirby Crossing (Williams et al., 2019). Conversely, warmer conditions caused by global warming also intensify the hydrological cycle, inducing extreme precipitation events like floods near coastlines (Tabari et al., 2020). These climate intensifications place coastal regions at risk for future flooding and establish the scenario of extreme precipitation to be a possible concern for Kirby Crossing, which is to be explored in the proposed MR system in conjunction with wildfire scenarios.

RELATED WORK

A. Virtual Immersion and Empathy

The inherent immersion of MR and VR has received attention in the HCI (Human-Computer Interaction) community as a potential tool for inspiring empathy and inciting action. The “Virtual Seafood Buffet” (Pimentel et al., 2019) is a VR experience that allows users to pick from various seafood items and visualize the degradation experienced by that particular species. Studies involving Virtual Reality Perspective-Taking (VRPT) tasks—tasks that enable users to experience the perspectives of others—support the proposed effectiveness of VR simulations in communicating messages through immersion. Findings suggest that VRPT tasks correlate to increased prosocial behaviors and empathy, demonstrating the successful transfer of empathy from the virtual to the physical world. For example, users who experience the action of cutting down a tree in an immersive VR format can be expected to show an increased inclination to conserve paper (Mado et al., 2021). By placing users precisely in the middle of an issue, researchers achieved success in transferring perspectives through constructing immersive virtual experiences.

B. Climate Change Misconceptions and Implications

Persistent and subjective beliefs on the causes of climate change, especially those that are nonscientific, place policies at risk and weaken support for climate change initiatives (Fleming et al., 2021). Researchers have correlated environmental misconceptions with two factors: the perceived harm caused by climate change, and their ability to interfere with climate change. Support for climate change policies varies directly based on public perception of climate change risks.

The effort to discredit the scientific consensus on the reality of climate change has been continuing without signs of decline. The United States’ ideological commitment to laissez-faire policies and opposition to strict regulation fuel climate change denial and contribute to a passive society that will allow climate change to persist (Collomb, 2014).

A systematic quantitative review of the literature surrounding climate change engagement identified gaps in scientific and local knowledge, particularly in developing countries (Khatibi et al., 2021); gaps in existing literature surrounding climate change engagement methodology calls for effective public engagement in climate change policies through literary and scientific motivators.

METHODS

In order to examine MR's ability to transform abstract concepts into realistic experiences, we devised and implemented a proof-of-concept system with the Unity Engine and Microsoft's Mixed Reality Toolkit. We then conducted a pilot study and collected data pertaining to the efficacy and strengths of our system.

A. Implementation

To simulate a localized environment under heavy damage from climate change, we constructed an MR environment for the Microsoft HoloLens 2. The virtual environments were constructed using Unity 2019.4.2f1 and developed with Mixed Reality Toolkit version 2.7.0; both virtual environments were constructed on top of a scanned physical environment based on Kirby Crossing, a location on the University of California, Santa Barbara campus; the LiDAR-scanned environment was provided by the UC Santa Barbara Four Eyes Lab, which set up the platform of our research.

FIG. 1. Flood and tornado simulation featuring oscillating water plane and spinning tornado asset

FIG. 2. Fire simulation featuring randomly spawned fire particle systems

Our system consists of two scenes simulating possible future scenarios for Kirby Crossing, with both possibilities being based on historical climate change anthropogenic trends and models; both scenes demonstrate potential consequences of climate change. One scene simulates the environment under heavy flooding and tornados, and the other simulates the environment under chaotic fire. 3D elements were added to each scene to simulate the environment under natural disasters.

Fig. 1. shows the flood and tornado simulation scene, where a flooded environment was simulated via an animated and textured water-plane that was instantiated at program runtime. The simulated water level is manipulated throughout the navigation experience via a C# script in order to simulate a realistic experience and provide a sense of urgency to the user. On program execution, the water begins at a defined height close to the Kirby Crossing ground level. As the simulation proceeds, the water height oscillates between the initial level and a higher level that submerges users. Tornados constructed using the Unity Particle System are also generated and displayed at program runtime. These tornadoes engage in circular movements around predetermined points in the scene (Mandapuram, 2017b). Scripts are used to manipulate the tornado's speed and behavior. To simulate realistic flooding visualizations, an underwater effect is implemented via a C# script. Previous work, including work conceived in an AR format at Kirby Crossing, indicate that virtual objects are more perceptually challenging to discern in conditions consisting of direct sunlight (Kim, 2022). To minimize the dueling focus effect, we simulated an environment to be experienced in a dull and cloudy setting via a custom skybox.

Fig. 2. displays the fire simulation scene. The fire simulation scene is modeled with a C# script that controls the spawning of fires built with the Unity Particle System. These fires spawn randomly in each section of the virtual environment, slowly spreading from one section to another. To simulate a chaotic environment, we modeled and generated cracked crates falling from the sky. 3D objects in the scene are manipulated with the RigidBody component for realistic physics simulations, while user collisions were prevented with added mesh and box colliders to virtual map objects. A first-person controller was utilized to manage movements and player inputs. A main menu was added to allow for program navigation and scene selection.

FIG. 3. First-person view of simulated scenes in (a) daylight, (b) flooding scenario, and (c) fire scenario.

First-person perspectives of system users is shown in Fig. 3. Section (a) shows an unaltered 3D scan of Kirby Crossing, which set up the foundation for (b) and (c). Lighting conditions and virtual objects are superimposed on the unaltered environment, and resulted in two scenes that simulate a tornado with floods and a spreading fire, as seen in (b) and (c) of Fig. 3.

B. Data Collection

Our methods can be evaluated using performance and efficacy metrics pertaining to the Mixed Reality experience. The efficacy of our system depends on several factors, including the duration of the MR experience, the user's stress tolerance, and the user's preconceived notions about climate change. A pilot study was conducted in order to evaluate our methods and gain a better understanding of the system's strengths and weaknesses (Mandapuram, 2017a).

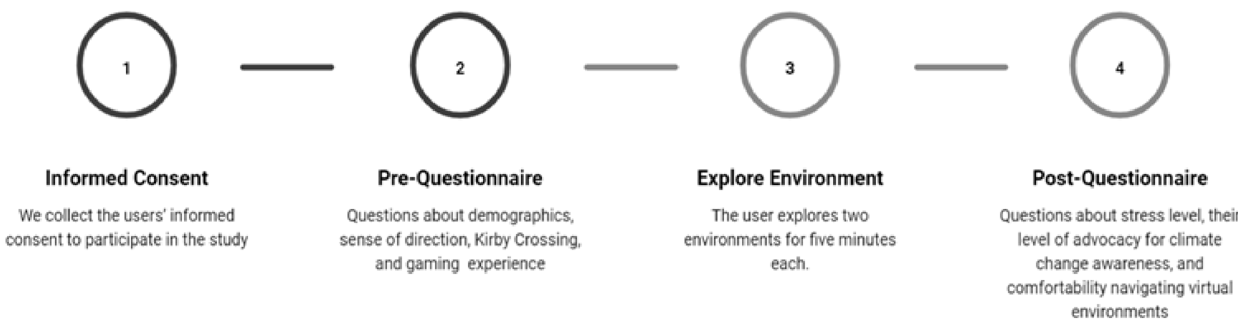

FIG. 4. Study Timeline consisting of four main steps experienced by study participants

To evaluate our system and understand its benefits over other interactive media platforms, we conducted a user study consisting of nine participants. Most participants were family members, relatives, friends, and colleagues of the researcher. The participants varied in age and MR experience, with ages ranging from 15 to 53 years. 33.3% of the participants identified as male, and 66.7% as female. None of the participants reported any sensory, perceptual, or cognitive impairments.

Participants in this study were not selected based on experience and did not share prior knowledge about MR, AR, or VR. A timeline of the study and data collection method is shown in Fig. 4. After collecting the participants' informed consent, we instructed the participants to complete a pre-questionnaire consisting of sections that include demographics, sense of direction, Kirby Crossing experience, and gaming experience. We asked the participants to rate their stress levels, their level of advocacy for climate change awareness, and comfortability navigating virtual environments on a numeric scale. The entire survey consisted of seven multiple-choice questions and seven questions with 10-point Likert scale responses.

After exploring the simulated environment, we asked the participants to complete a post-questionnaire. We collected feedback from the participants about the navigational difficulty, their stress levels, and their opinions about adopting more environmentally friendly practices. Quantitative data collected include the numeric rating of their stress levels traversing through the environment, and qualitative data collected include indications about climate change awareness. This survey consisted of seven multiple-choice questions and one question with a 10-point Likert scale response.

RESULTS & ANALYSIS

FIG. 5. User-reported stress levels before and after study

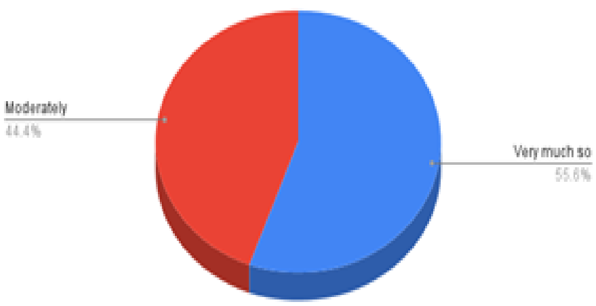

FIG. 6. User responses on the realism of the simulation

A. Overall results

The virtual experience we have constructed through Mixed Reality allows users to explore two different systems, a flood and tornado simulation as well as a fire simulation (Mandapuram, 2016). Fig. 5. indicates an increase in general stress levels after exploring the virtual environments. The average increase in stress was 0.667, signifying a correlation between system use and increased magnitudes of stress level, yet not indicating signs of severe psychological effects caused by significant magnitudes of stress increases.
Results from the user study most strongly indicate that users believed that the disaster sequences shown were realistic in representing potential future scenarios based on climate change effects, as shown in Fig. 6. One hundred percent of users responded that MR and AR offer more tangible and realistic experiences in comparison to other forms of dissemination, including, but not limited to, videos and digital posters. These responses show potential correlation with factors implemented to simulate realistic experiences, including visually-tangible objects such as constructed flames, floods, and falling crates.

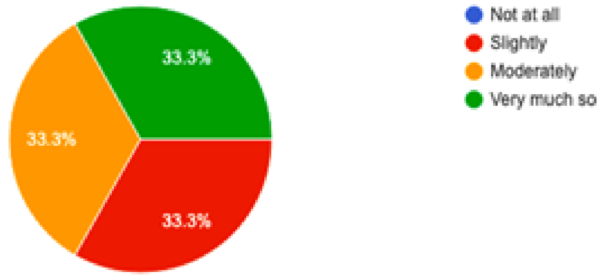

FIG. 7. Inclination to adopt environmentally friendly practices after testing based on a study with 9 users

Collected results suggest that the proposed MR system marks a viable pathway to provide deep immersion and awareness of the effects of climate change. Collected results from the pilot study suggest a positive user connection between MR use and practical means of visualizing climate change. Fig. 7. the responses of surveyed individuals on their inclination to adopt environmentally-friendly practices. All responses indicated a positive magnitude of inclination, with 33.3% of responses indicating "very much so."

DISCUSSIONS & CONCLUSIONS

As climate change misconceptions persist while its effects increase at an exponential rate, it becomes increasingly necessary to visualize the effects it will have on our world. We present a unique and immersive system that contextualizes the abstract topic of climate change in an interactive format in order to incite action toward slowing the anthropogenic effects of global climate change. Results from our study have shown MR's potential to provide greater magnitudes of immersion than other forms of dissemination, and its ability to inspire users to adopt more sustainable lifestyle practices. An important metric to evaluate MR systems is induced nausea, which we examined in post-questionnaires of our user study. Results indicate no reported headaches, eye strains, blurred vision, or dizziness throughout the MR experience, confirming the general stability of our system and establishing the potential of fully immersive technologies in spreading awareness on issues like climate change.

Due to the lack of accessibility of Head-Mounted AR Displays, our pilot study is confined to a Mixed Reality format. However, the possibilities of this research are expansive. Future work can take advantage of opportunities to construct more realistic and localized scenarios, which may correlate to increased magnitudes of climate change contextualization, measured through stress level increases or user-reported increases in inclination. which may include implementing real-time scanning and geographical mapping, dynamic object placement, information prompting, and improved spatialized audio.

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