

Innovative Application and User Experience of Virtual Reality Technology in Human-Computer Interaction

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Abstract. Virtual Reality (VR) technology has emerged as a transformative force in the realm of Human-computer interaction (HCI), offering novel applications and redefining user experiences. VR games have changed traditional electronic games, providing a human-computer interactive immersive gaming experience. In social media, VR innovative applications allow users to have an immersive conversation through various interactions, giving users a more immersive and real experience. The paper synthesizes recent research findings, highlighting key trends, challenges, and opportunities in the integration of VR into HCI and illustrates the embodiment of immersive experiences while using VR compared to the traditional way. At the same time, the challenges associated with VR technology such as motion sickness, accessibility concerns, ethical considerations, and medical challenges, are also discussed, offering a balanced perspective on the current state of the field. The future development perspective is also mentioned. As technology continues to evolve, we can expect to see even more immersive and interactive experiences that blur the lines between the physical and virtual worlds, offering users new ways to engage with digital content and each other.

Keywords: Virtual Reality, immersive experience, Human-computer interaction.

1. Introduction

Virtual Reality (VR) technology provides a virtual place and simulated experience that uses pose tracking and 3D near-eye displays to give users an immersive experience in the virtual place. This technology finds applications across various sectors, including entertainment, particularly in the realm of video games, as well as education, where it is utilized for purposes such as medical and military training. In addition, enterprises use VR to conduct virtual meetings and enhance the collaboration experience. The broader VR-style technology includes augmented reality (AR), mixed reality, and the evolving concept of extended reality (XR), reflecting the dynamic changes in industry definitions driven by the continued growth of this transformative area.

The emergence of VR is undoubtedly a major invention, which attracts many people to the field of virtual reality with its immersive experience and the new experiences of Human-computer interaction function. The significance of this research lies in VR's profound impact on human experience and interaction. By exploring current conceptual frameworks and applications, we gain insight into the evolving nature of human-computer interaction. This exploration is particularly important because virtual reality is not only reshaping traditional industries but also laying the foundation for new possibilities for communication, education, and collaboration.

The motivation behind this study stems from the recognition that although VR has made significant progress in transforming human-computer interaction, there is still a need for a more comprehensive understanding of its diverse applications and user experiences. Existing research often lacks a thorough exploration of the challenges associated with VR technology and its potential impact on areas such as healthcare and social interaction. This study aims to bridge these gaps, synthesize the latest research results, and provide a nuanced perspective on the integration of VR with HCI. By delving into innovative applications and user experiences, we aim to provide valuable insights and promote more informed discussions about the current state and future possibilities of VR technology.

2. Innovative applications in human-computer interaction

This chapter will conduct an in-depth study of the innovative applications of VR in human-computer interaction, focusing on the fields of education and medical care. As technology continues to advance, VR technology has become a key tool in changing the way learning and medical practice are conducted. In education, VR provides students with an immersive learning experience, stimulating interest and in-depth understanding; in the medical field, it creates an immersive diagnosis and treatment environment to support surgical simulation and psychological treatment. At the same time, it will also explore innovative applications such as virtual laboratories and distance learning in education, as well as surgical simulation and mental health therapy in healthcare. Through specific case studies, we will reveal how VR plays a unique role in human-computer interaction and promotes innovation in education and medical fields. By studying these applications in depth, we are expected to gain a more comprehensive understanding of the potential of VR in human-computer interaction and provide useful enlightenment for related fields.

2.1. Application of VR in the Education Sector

2.1.1. VR Education Cases

VR technology is disrupting traditional education models and triggering a wave of change, immersing learners in dynamic and interactive environments. The primary way to access VR is through dedicated headsets like the Meta Quest, Sony PlayStation VR, or Apple Vision Pro. Students can explore, move, and interact with virtual environments, expanding their horizons of potential applications.

From virtual museum tours to simulated surgical training for medical students, VR's versatility covers a variety of scenarios. In educational settings, VR can transport students to otherwise inaccessible locations, allowing virtual visits to cultural sites or experiences of time travel, all within the confines of the classroom. Compared with traditional education methods, virtual reality can be a medium for knowledge dissemination. Through its immersive characteristics, it provides more new perspectives from different dimensions in the explanation and understanding of knowledge points, allowing students to understand and comprehend more intuitively. Experience knowledge through virtual reality technology and promote educational development.



Figure 1. “Vector van Gogh” interactive task. Participants’ gestures were captured with the Kinect sensor as they drew a vector (yellow arrow) in 3D space [1]

Throughout the lesson, students used a variety of highly embodied and posture-consistent movements to facilitate learning (Fig. 1). This screenshot shows the "Vector van Gogh" simulation, in which users may sketch vectors [1]. In this example, the right wrist joint is tracked at high embodied conditions using the Kinect 360 sensor. Students interact with the human machine by changing their posture and movements so that the sensor can capture their gestures and trigger interactions. At the

same time, learners were free to create vectors of different sizes by simply waving their arms in large or small embodied gestures. With this immersive VR environment, student motivation is increased.

Compared with the traditional education, the advantages of the VR education are as follows:

Immersive Learning Environments: Virtual Reality education provides immersive and interactive learning environments that allow students to learn in a more hands-on manner and deepen their memories.

Real-world simulations: Virtual reality technology allows for realistic simulations that are especially beneficial in areas such as dangerous experiments in medicine, engineering, and chemistry. Students can practice skills and procedures in a risk-free virtual environment and apply them to real-life situations as they gain experience.

Global Resource Access: Virtual reality technology facilitates global access to educational resources in different geographic locations. Students can break down geographic barriers by virtually immersing themselves in historical sites, exploring cultural landmarks, or engaging in collaborative projects across geographies with peers worldwide to promote cultural integration.

Innovative Teaching Methods: Virtual reality encourages educators to explore new and innovative teaching methods actively. They can design interactive lessons, incorporate gaming elements, and use 3D models to explain complex concepts and make learning more engaging.

2.1.2. Learning Outcomes and Effects & Enhancement of Student Experience

VR in education has shown significant potential in enhancing learning outcomes and bringing about various positive effects.

(1) **Increased Engagement:** immersive VR creates a captivating and interactive learning environment, promoting higher levels of engagement among students. The sense of presence and the ability to interact with 3D environments make learning more dynamic and memorable.

(2) **Accessibility and Inclusivity:** VR offers inclusive learning experiences, accommodating various learning styles and abilities. Students with different preferences, such as visual or kinesthetic learners, can benefit from the multi-sensory engagement provided by immersive VR.

(3) **Simulation-based Training:** VR is particularly effective for simulation-based training in professions such as healthcare. Medical students, for example, can practice surgeries or diagnostic procedures in realistic virtual scenarios before entering a clinical setting.

Studies by learning domain

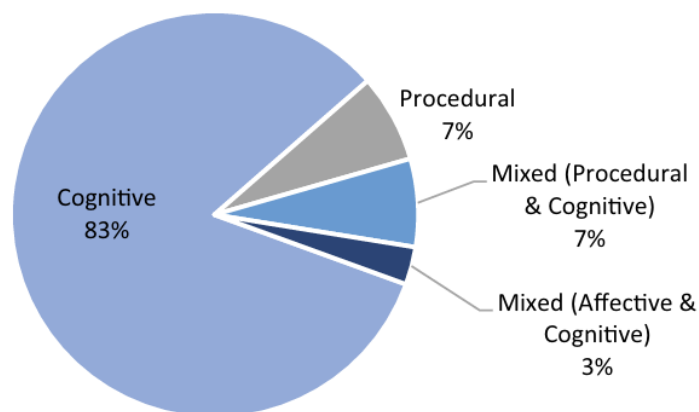


Figure 2. Percentage of papers per learning domain [2]

The analyzes conducted in this review comprehensively explore learning outcomes in three different domains: cognitive, procedural, and affective (shown in Fig. 2). Notably, examinations demonstrated an emphasis on the teaching of cognitive skills and knowledge, which was the primary focus of 83% of the studies in this review [2]. Nearly half of the studies show that utilizing VR can have a positive impact on learning outcomes compared to less immersive teaching methods. Most of the remaining studies did not show significant effects in either direction, and only a few papers reported adverse results. For learning outcomes, VR had a learning benefit in about half of the

cognitive studies, especially in the case of highly complex or conceptual problems requiring spatial understanding and visualization.

However, there are still gaps in understanding emotional behavioral changes in VR educational applications. Although extensive research has been conducted in non-educational contexts, this area remains under-researched, suggesting that this is an important area for future research. Furthermore, due to the novelty of the technology, short exposure times and isolated interventions can be problematic and thus hinder knowledge uptake. Encouragingly, procedural tasks often benefit from VR, demonstrating its effectiveness in skill learning. The transferability of virtual skills to real-world scenarios is a positive outcome that exemplifies the potential of VR for real-world applications.

2.2. Innovation in VR in Healthcare

In recent years, with the integration of VR technology, VR has not only innovated in the field of education but has also undergone significant changes in the healthcare industry. VR uses its unique virtual simulation human-computer interaction technology and 360-degree perspective to innovate medical training and simulation, patient rehabilitation and treatment, and remote consultation and telemedicine in the field of healthcare.

(1) Healthcare Training and Simulation: VR-based simulations provide healthcare professionals with hands-on training in a safe and controlled environment. Among them, VR gamification immerses learners in-game elements and technology for learning, and of course, plays a treasure hunt-type game where their task is to find and understand potential interventions for patients. After they learn about potential interventions (Fig. 3), learners are asked to reflect on and evaluate their identification results to consider their factual plans for intervention [3]. VR technology attracts learners' interest in learning influences their behavior through gamified training methods, and improves their knowledge mastery through clear tasks, victory status, and feedback.

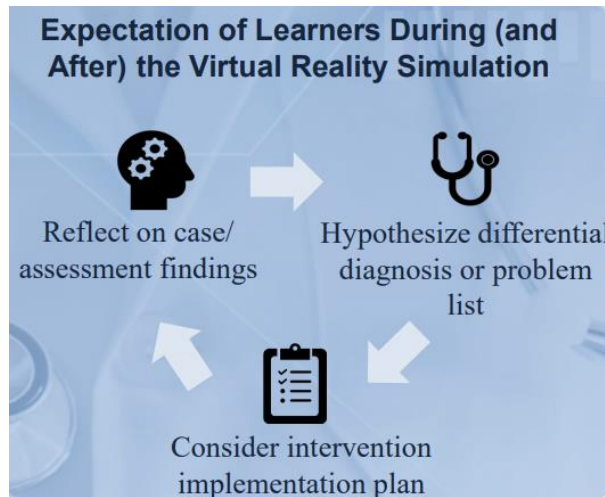


Figure 3. Expectations of Learners During (and after) the Virtual Reality Simulation [3]

(2) Patient Rehabilitation and Treatment: VR-based rehabilitation programs provide personalized and immersive experiences for patients recovering from injury or surgery. Physical therapists can design interactive exercises based on a patient's individual needs, promoting faster recovery and better outcomes.

The technology behind it is Applied VR's Soothe VR, a commercially available headset that comes preloaded with a variety of immersive experiences (Fig. 4). These experiences include guided meditation sessions in realistic natural settings, passive or active exploration of outdoor environments (such as swimming with dolphins, touring world cities), and cognitively stimulating games such as navigating a maze or aiming a virtual ball at a target. These modules feature soothing three-dimensional natural environments such as coastlines, underwater scenes, and twilight lands [4].

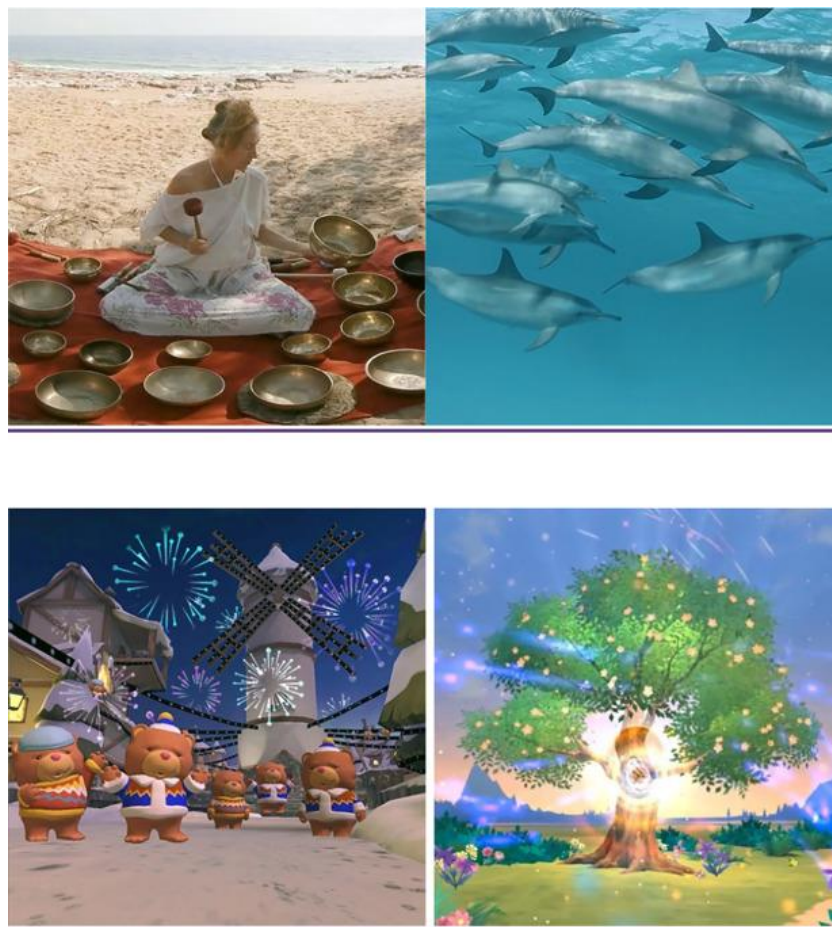


Figure 4. Sample backgrounds of VR modules [4]

(3) Teleconsultation and telemedicine: Teleconsultation and telemedicine enable patients to receive medical advice and consultation at home, eliminating geographical barriers and reducing the need to travel to a medical facility in person. VR enhances the telemedicine experience by providing immersive consultations and saves patients and healthcare providers time and money. Overall, VR telemedicine improves access to care and enhances the patient experience.

2.2.1. Medical Application Cases: Patient Rehabilitation Treatment

VR technology has become a new tool inpatient rehabilitation and treatment, providing innovative treatment solutions in various medical fields. Here are some noteworthy applications:

(1) Physical Rehabilitation: Virtual reality-based rehabilitation programs offer interactive exercises and simulations to meet the specific needs of patients recovering from injury or surgery. For example, patients receiving physical therapy for musculoskeletal injuries or neurological conditions can perform virtual exercises that target specific muscle groups or improve coordination and balance. These immersive experiences enhance patient engagement and motivation, leading to better recovery outcomes.

(2) Neurorehabilitation: VR technology is increasingly used in neurorehabilitation to help restore motor function and cognitive abilities after neurological injuries or conditions such as stroke or traumatic brain injury. Patients can engage in virtual activities that mimic real-life tasks, such as reaching for objects, navigating virtual environments, or performing activities of daily living. These virtual exercises help stimulate neural pathways, promote neuroplasticity, and promote functional recovery in affected brain areas.

(3) Pain Management: VR has the potential as a non-pharmacological intervention for pain management in patients with chronic pain or undergoing painful medical procedures. By immersing patients in a virtual environment that distracts and relaxes them, VR can reduce perceptions of pain and anxiety. For example, patients undergoing wound care or dental procedures can use VR headsets

to immerse themselves in a calming virtual environment, effectively reducing pain levels and improving the overall patient experience.

(4) **Mental Health Treatment:** VR therapy is recognized as an effective treatment modality for a variety of mental health conditions, including post-traumatic stress disorder (PTSD), anxiety disorders, and phobias. Patients can enter a virtual environment that simulates real-life situations, allowing them to face and manage their symptoms in a safe and controlled environment. For example, people with post-traumatic stress disorder can undergo virtual exposure therapy to gradually confront and process traumatic memories, thereby reducing symptoms and improving mental health.

2.2.2. Challenges and Limitations

While VR technology has great potential for healthcare applications, many challenges and limitations must be addressed to fully exploit its capabilities and ensure its safe and effective implementation:

Financial constraints and accessibility: The initial investment in VR hardware and software places a significant financial burden on healthcare organizations, especially small clinics or clinics with limited resources. Additionally, ongoing maintenance costs and software updates can put pressure on already tight budgets. Additionally, accessibility barriers may arise for patients who do not have access to VR technology or lack the technical proficiency to utilize the technology effectively.

Technical Barriers: Despite continued advancements, current VR hardware and software still encounter technical limitations. Issues such as motion sickness, latency, and visual discomfort may impact the immersive experience, potentially limiting its applicability in certain patient populations. Additionally, the need for high-quality graphics and processing power can make real-time rendering of complex virtual environments challenging, especially in resource-constrained environments.

Ethical and Privacy Issues: The integration of VR into healthcare raises ethical and privacy issues. Protecting patient data collected during VR sessions, including movement patterns and physiological responses, is critical to ensuring patient confidentiality and compliance with privacy regulations. Additionally, VR therapy may lead to addiction or dependence, requiring vigilant monitoring and ethical oversight to safeguard patient health.

Integration with existing healthcare infrastructure: Integrating VR technology into existing healthcare systems presents complex challenges. Compatibility issues with electronic health record (EHR) systems, interoperability with medical devices, and disruptions to clinical workflows can hinder seamless integration. Additionally, healthcare professionals may require specialized training to effectively utilize VR technology in clinical settings, further complicating adoption efforts.

3. Social impact of virtual reality technology and prospects

The social impact of VR technology is huge, with the potential to transform every aspect of society and human interaction. VR has the power to transform communications, entertainment, education, and healthcare by delivering immersive, interactive experiences that can bridge geographic distances, foster empathy and understanding, and enhance learning and collaboration. Additionally, VR has the potential to democratize experience and opportunity, providing new avenues for creativity, expression, and social interaction. As its technology continues to evolve, it has considerable promise in shaping the future of society, with the potential to create more connected, caring, and inclusive communities.

3.1. Virtual Reality in Social Interaction

VR technology has emerged as a powerful tool for improving social interactions and creating connections across multiple environments. VR enables people to interact with others in virtual environments that mimic real-world interactions by providing immersive and engaging experiences. In addition to being innovative, this technology also acts as a catalyst for social change by establishing a platform that breaks down barriers of distance and encourages interpersonal relationships and communication.

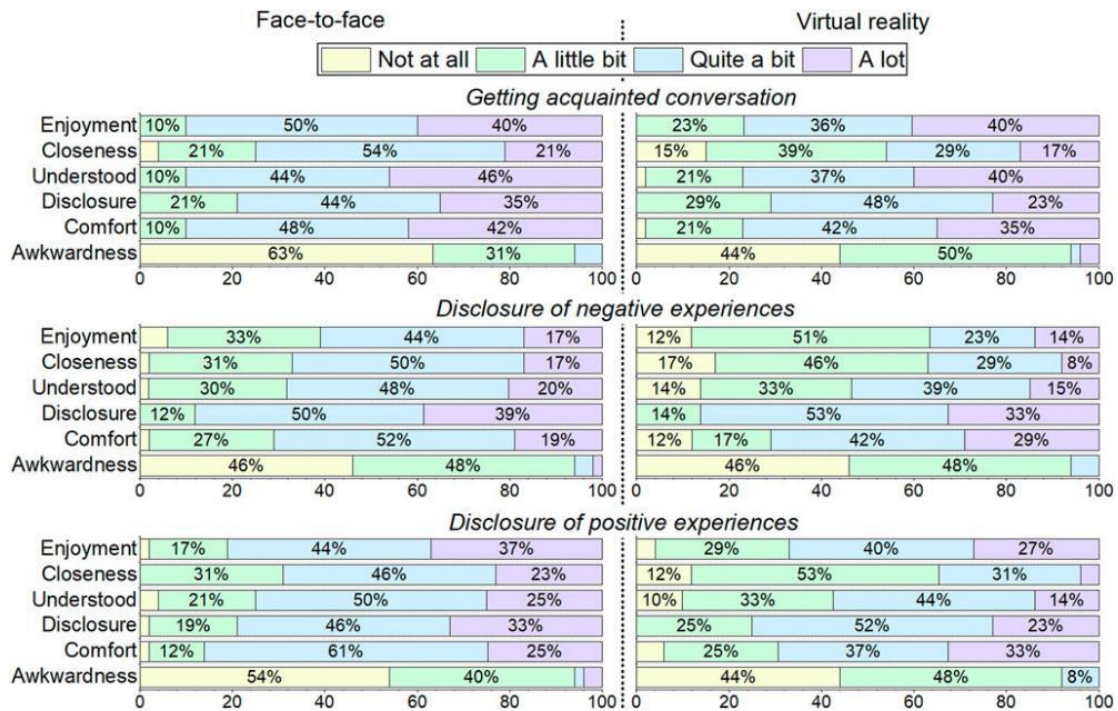


Figure 5. Participants' evaluations on their experiences having conversations in virtual reality and in various face-to-face communication contexts [5].

An important application of VR in the social field is the virtual social platform, where users can meet, communicate, and collaborate in a virtual space. Regardless of where they are physically located in the world, these VR platforms give people the opportunity to have meaningful relationships with a wide range of people, including friends, family, coworkers, and even people they have never met. Users can attend virtual events, attend conferences, or simply hang out in shared virtual spaces, cultivating a sense of presence and connection that transcends physical boundaries. There were no significant disparities observed between face-to-face and VR interactions for familiar conversations regarding enjoyment, understanding, self-disclosure, comfort, and awkwardness ratings (Fig. 5). Across both face-to-face and VR settings, ratings for elements such as enjoyment, understanding, disclosure, and comfort were notably consistent, typically falling within the 71% to 90% range. Concerning awkwardness ratings, a large majority of individuals—95% and 94% respectively—indicated minimal discomfort, with slight awkwardness reported in both face-to-face and VR scenarios. The only discernible contrast in ratings was noted in terms of intimacy level, with 75% rating it substantially higher for face-to-face interactions compared to 46% in VR. Regarding the disclosure of unpleasant experiences, there were no notable distinctions between in-person and virtual reality in terms of the disclosure and comfort ratings descriptors. The results for the disclosure of bad experiences paralleled the differences between face-to-face and virtual reality in terms of positive experience disclosure [5].

3.1.1. Virtual Social Platform

Virtual social platforms represent a burgeoning frontier in digital communication, offering immersive environments for social interaction and collaboration. These platforms enable users to connect and engage with others in virtual spaces, transcending the limitations of physical distance and fostering a sense of presence and connection.



Figure 6. VRChat propaganda screenshots [6]

VRChat is a multiplayer online VR game launched in 2017 (Fig. 6). As virtual social platforms continue to advance and gain widespread acceptance, they hold the potential to transform our methods of connection and communication in the digital era. These platforms offer immersive and interactive environments for social interaction, presenting novel opportunities for cultivating relationships, fostering collaboration, and sharing experiences. For instance, VRChat provides users with the ability to customize their avatars, design virtual spaces, engage in conversations with other users, and participate in various activities such as watching movies or playing games with friends. Its remarkable degree of flexibility and creativity has propelled its popularity, with user numbers surpassing 4 million by early 2019 [6].

One of the key advantages of virtual social platforms is their ability to facilitate meaningful social interactions and experiences. Users can attend virtual events, participate in group activities, and collaborate on projects in real time, fostering a sense of community and belonging. Moreover, virtual social platforms offer opportunities for users to explore new interests, connect with like-minded individuals, and form lasting friendships.

Virtual social platforms also provide a safe and inclusive space for individuals to express themselves and interact with others without the constraints of physical appearance or social status. This inclusivity promotes diversity and acceptance, creating an environment where individuals from different backgrounds can come together and share their experiences and perspectives.

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3.2. Ethical and Privacy Issues

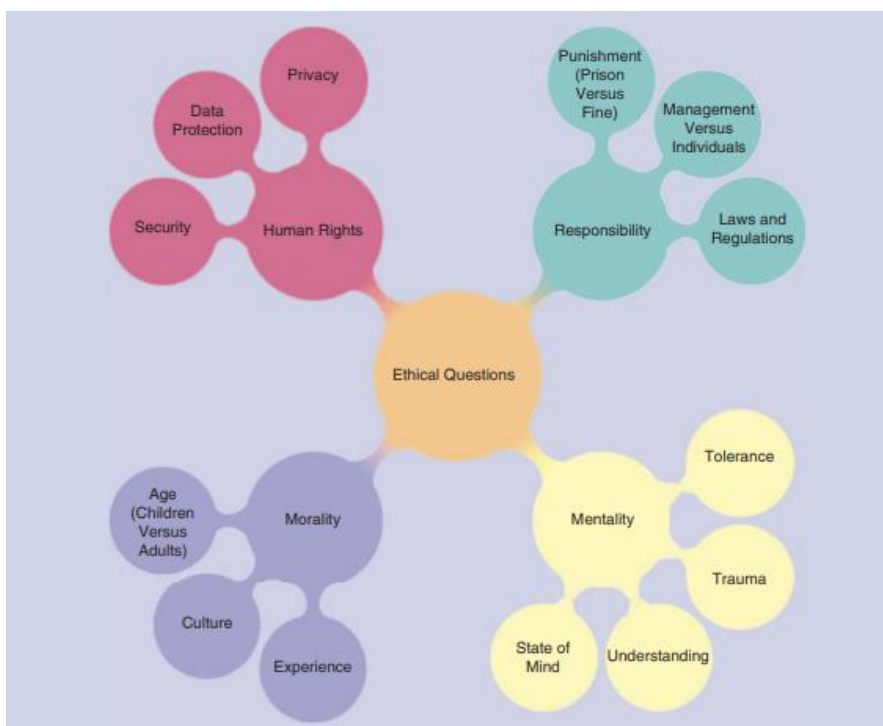


Figure 7. Ethical questions and challenges around VR technologies [7].

As virtual reality becomes increasingly integrated into every aspect of daily life, it brings with it a host of ethical and privacy issues that must be addressed to ensure responsible and ethical use. (Fig. 7)

One of the main concerns is related to privacy, as VR systems often collect large amounts of personal data during use, including biometric information, movement patterns, and interactions with the virtual environment. Securing this sensitive data is critical to protecting user privacy and preventing potential misuse or unauthorized access. Additionally, ensuring transparency in data collection practices and obtaining informed consent from users are fundamental ethical considerations in VR development and deployment.

Another ethical consideration concerns the issue of digital identity and representation in virtual environments. Users can create personalized avatars or virtual characters that differ significantly from their real-world identities, raising questions about authenticity, identity theft, and misrepresentation. It is critical to ensure that users have control over their digital identities and can ethically manage their online presence [7].

Furthermore, the ethical implications of VR are not limited to individual users but also have wider social impacts, such as potentially exacerbating social inequalities, reinforcing stereotypes, or perpetuating harmful behaviors [8]. Ethical frameworks and guidelines are needed to address these broader social impacts and promote ethical design practices that prioritize social responsibility and justice.

3.2.1. Ethical Challenges

1. Codes of conduct: Virtual social platforms often lack established codes of conduct, leading to uncertainty about appropriate behavior and interactions [9]. Ethical challenges arise when establishing ethical guidelines and norms for user behavior in virtual environments.

2. Content Moderation: Ensuring appropriate content moderation on virtual social platforms poses ethical challenges due to the sheer volume and diversity of user-generated content. Platforms must address ethical issues around censorship, free speech, and their responsibility to reduce the spread of harmful or offensive content.

3. Inclusion and Diversity: Promoting inclusion and diversity on virtual social platforms raises ethical considerations around representation, accessibility, and discrimination. Platforms must work to create inclusive environments that accommodate users from diverse backgrounds while addressing issues of bias, discrimination, and exclusion.

4. Cybersecurity: Protecting users from online threats, harassment, and exploitation poses ethical challenges to virtual social platforms. Platforms must implement strong cybersecurity measures and security protocols to protect user data and reduce the risk of cyberbullying, harassment, and online exploitation.

4. Future trends and prospects

Looking forward, the future of VR holds promising developments that anticipate significant advancements in various aspects. Enhanced immersion through improved graphics, interaction capabilities, and sensory feedback will create more lifelike and engaging virtual experiences [10]. Furthermore, the expansion of VR applications beyond entertainment into areas such as education, healthcare, and remote collaboration will unlock new opportunities for innovation and utility. Increased accessibility and inclusivity efforts will ensure that VR technologies become more widely accessible to diverse user populations. Additionally, seamless integration across different platforms and devices will facilitate seamless interactions and connectivity in virtual environments. As VR continues to evolve, addressing ethical considerations around privacy, data security, and digital identity will be paramount to ensuring responsible and ethical use of these technologies. Overall, the future of VR is poised to redefine human experiences, interactions, and possibilities in ways that were previously unimaginable.

5. Conclusion

In summary, the exploration of innovative applications of VR technology and user experience in HCI reveals the transformative potential in various fields. In education, VR has demonstrated its power to improve learning outcomes and student experience through immersive and interactive environments. The ability to create realistic simulations and personalized learning paths marks a paradigm shift in the approach to education. Additionally, VR applications in healthcare are showing significant advancements from medical training simulations to therapeutic interventions. Despite significant success, challenges remain, including technical limitations and the need to overcome complex design issues. Future efforts in this area should focus on refining VR technology to address these challenges and unleash its full potential to revolutionize medical practice. On the social side, VR technology has made significant progress in shaping new interaction models through virtual social platforms. However, ethical issues and privacy issues have become key considerations. Striking a balance between innovation and upholding ethical principles is critical to the continued development and social acceptance of VR technology.

Looking to the future, the continued development of VR technology holds great promise. Further research should delve into the history and technological development of virtual reality and examine its interactions with users at different times.

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