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Virtual Simulation in Healthcare Education: Trends, Applications, and Future Directions

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Abstract

Keywords::

Virtual Reality, Simulation Training, VR Acceptance, Interactive virtual reality, Performance expectancy.

Virtual Reality technology is reshaping healthcare education by offering immersive and interactive learning experiences that surpass conventional methods. This study explores current trends, applications, and future directions of VR in healthcare education, emphasizing its role in augmenting learning outcomes and enhancing patient care. VR applications in medical education allow students to participate in realistic simulations of surgical procedures and patient care scenarios, fostering the acquisition of practical skills and decision-making abilities. These simulations standardize training protocols and ensure consistent evaluation of clinical competency, thereby improving patient safety. The integration of VR in medical training addresses challenges related to accessibility and inclusivity by democratizing access to high-quality education regardless of geographical or physical constraints. This study employs a semi-exploratory approach to assess the acceptance and effectiveness of VR simulations in healthcare training. The research underscores the positive impact of a strong sense of presence on behavioral intentions towards VR learning. However, it notes a negative correlation between spatial presence and knowledge improvement, underscoring the necessity for improved measurement tools and further research. As VR evolves within healthcare education, comprehending these dynamics becomes crucial for optimizing educational strategies and outcomes. In conclusion, VR technology holds immense promise for transforming healthcare education by offering unparalleled immersive experiences that enhance learning effectiveness and clinical competency. By addressing accessibility barriers and refining simulation methodologies, VR not only enriches educational experiences but also contributes significantly to improving patient care standards. Future research should continue to explore the nuanced aspects of VR integration in healthcare education.

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1. INTRODUCTION

Education is broadly defined as the process of enabling learning and the acquisition of knowledge, skills, and positive values. Its main objective is to prepare individuals for life, employment, and civic responsibilities by providing them with essential societal knowledge and skills. Educators strive to improve students' qualifications, competencies, and skills throughout their educational journey. Courses are generally divided into theoretical and practical components. Theoretical instruction involves knowledge transfer through lectures, which may include discussions, while practical components have become more prominent in response to evolving student needs and labor market demands. Reflecting Confucius' wisdom, "Tell me and I forget, show me and I may remember, let me take part and I understand," the emphasis on practical learning has increased (Confucius as cited in Goodwin & Miller, 2012).

Students often find it challenging to grasp complex scientific concepts due to their technical nature, the necessity for abstract thinking, and their intangible aspects. A lack of foundational knowledge can impede progress in more advanced areas. Practical exercises typically require specialized research equipment and must be supervised, limiting students' opportunities to practice independently or learn from mistakes outside of scheduled lab sessions. Modern technologies, such as online courses, blended learning, and various computer-based platforms, help students by providing opportunities to revisit topics, make mistakes, and learn from them. Successful uses of hardware and software in education showcase how the tech industry can significantly improve learning outcomes for many students. Educational institutions globally are increasingly adopting advanced technological tools to accommodate diverse student needs. Traditional textbooks are being supplanted by digital instructional materials, especially from open educational resources, while notebooks, tablets, and smartphones equipped with specialized applications are replacing traditional notebooks. Distance learning and personalized learning methods are customizing education to fit each student's individual strengths, weaknesses, preferences, and objectives (Smith & Doe, 2021). Recent advancements in information and communication technologies have notably improved student attitudes towards learning, driving ongoing innovation in educational technology. Virtual Reality (VR) has expanded beyond gaming into various professional sectors, including military operations, psychology, medicine, and education. VR was first defined by Jaron Lanier and Steve Bryson in 1987 as "the use of computer technology to create the effect of an interactive three-dimensional world where objects have spatial presence" (Lanier & Bryson, 1987). This concept, also known as I:3 (Interaction + Immersion + Imagination), primarily employs visual and auditory stimuli, sometimes adding tactile, olfactory, or gustatory elements. These sensory inputs are processed by the brain, creating a strong exchange of information with the simulated environment and altering perception of reality based on the sensory data provided (Johnson & Smith, 2020).

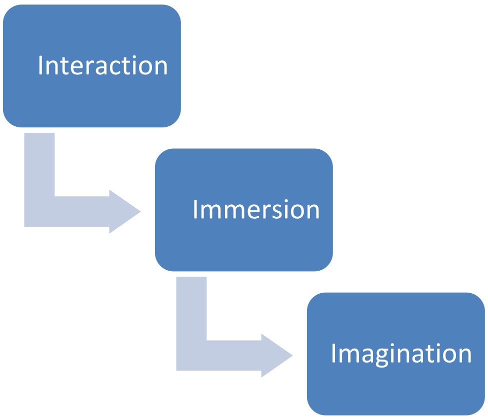

Figure 1: Virtual Reality Components

Virtual reality (VR) offers an interactive and immersive experience that transports users to entirely new environments. This capability makes VR a powerful tool for enhancing student learning and engagement. Educational VR content is designed to create realistic or imaginative virtual worlds where students can explore and interact with their surroundings. The fundamental concept behind using VR in education is that immersive experiences prompt students to engage more deeply, leading to better understanding of the subject matter. Because VR reduces the cognitive load required to process information, students can devote more cognitive resources to experiencing subjects like history, geography, science, art, and more firsthand (Daglar Cizmeci 2021).

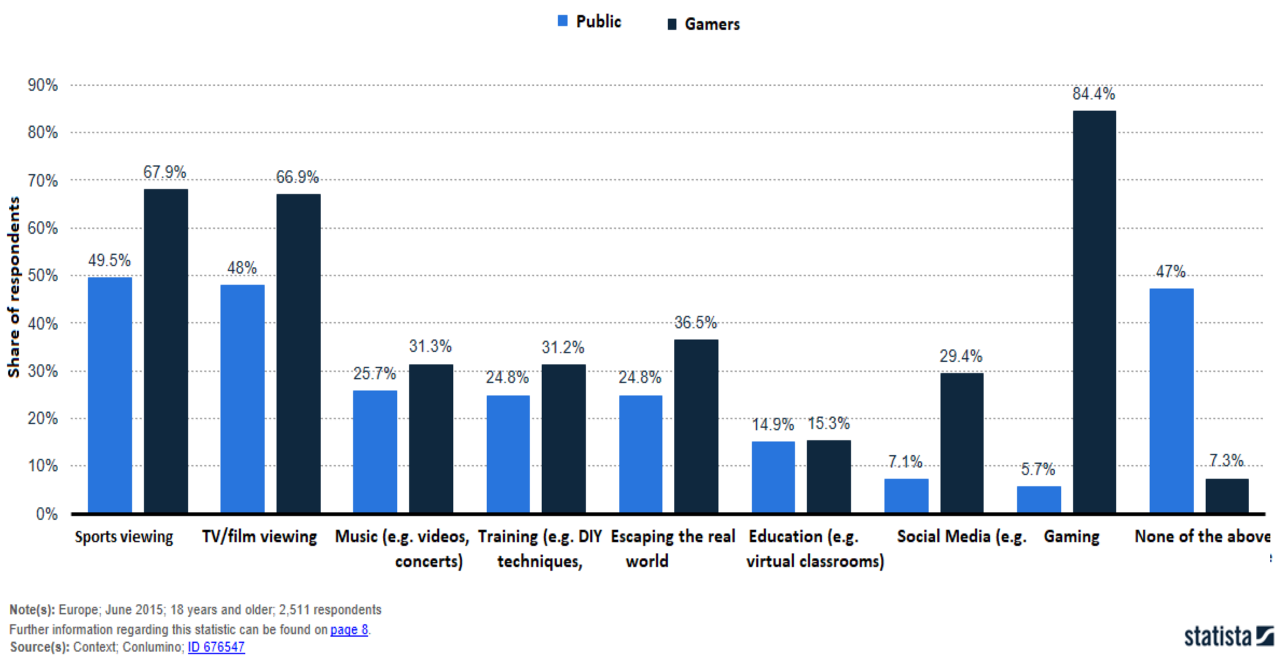

Figure 2: Ranking purposes for VR in Europe. Image: Statista

VR technology is now transforming healthcare education by providing immersive simulations for practicing surgical procedures and patient care in a risk-free environment. This enhances 5knowledge retention and supports modern learning models such as autonomous and blended learning (Pottle, 2019). The flexibility of VR caters to different learning styles and improves accessibility, making medical education more inclusive regardless of geographic or financial barriers (Kamińska et al., 2019). A balanced integration of VR with traditional educational methods ensures that technological advancements enhance essential human interaction and mentorship, ultimately leading to better learning outcomes and patient care.

This study delves into the realm of virtual simulation within healthcare education, exploring its current applications, evolving trends, and future directions. By utilizing secondary data sources, the research aims to examine the impact of virtual simulation on educational outcomes and user acceptance among healthcare practitioners. Through comprehensive analysis and empirical insights, this study seeks to underscore the transformative potential of virtual simulation in advancing training methodologies and improving clinical competence in healthcare settings.

2. Literature Review

Virtual Reality (VR)

Virtual Reality is a technology that generates an artificial, interactive three-dimensional environment using computer simulations. Users navigate and interact with objects and avatars within this virtual space, which frequently mimics the real world in terms of both visuals and physical behaviors, giving users a sense of being physically present in a fabricated environment. Currently, VR experiences are mainly provided through head-mounted display (HMD) systems. These head-worn or helmet-integrated devices include built-in screens and lenses. HMDs immerse users in virtual environments by offering a broad field of view, tracking head and hand movements, and allowing interaction with virtual objects using controllers. The launch of the Oculus Rift greatly increased VR's popularity, and interest in VR devices is still growing. Major corporations like Facebook, HTC, Google, Microsoft, and Sony are investing heavily in VR technology, exploring diverse applications for the hardware they develop. The market now includes a variety of HMD devices, from stationary, high-performance models like the Oculus Rift and HTC Vive to mobile VR headsets designed for smartphones, which have less processing power.

A comparison of the most popular HMD models is provided in Table 1, which offers a detailed overview of key specifications, advantages, and disadvantages. This information aids educators and institutions in making informed decisions about integrating VR into their curricula (Jones & Smith, 2021; Brown, 2020).

Table 1: Comparative Overview of Leading VR Head-Mounted Displays for Educational Use

Technology	**Resolution (DS)**	**Field of View (FOV)**	**Weight**	**Price**	**Advantages**	**Disadvantages**
HTC Vive Pro	1440 x 1600 per eye	110°	550 g	$1099	High resolution, large tracking area	Heavy, expensive, requires long setup time
Oculus Quest	1440 x 1600 per eye	90°	571 g	$500	High resolution, portable	Moderately heavy, smaller FOV compared to HTC Vive Pro
Samsung Gear VR	1480 x 1440 per eye (dependent on smartphone)	101°	345 g + smartphone	$130	Affordable, lightweight, portable	Dependent on smartphone performance, limited battery life, no positional tracking
Google Cardboard	Smartphone-dependent	90°	Smartphone weight	$7	Extremely affordable, lightweight, portable	Very limited functionality, dependent on smartphone performance, no positional

Virtual Reality (VR) has become a valuable tool for improving both learning and teaching processes. Different studies and reports suggest that students retain VR experiences more effectively than traditional laboratory-based demonstrations. Traditional laboratory methods often leave gaps in fundamental knowledge and practical skills, potentially leaving graduates unprepared for future career challenges. To mitigate these issues, innovative VR-based teaching methods are being proposed (Smith et al., 2021).

In educational settings, VR platforms often replicate traditional classrooms or laboratories but also provide a safe environment for practicing scenarios too complex or dangerous to conduct in real life. A proposed taxonomy for VR applications in education categorizes them by learning objectives into three main groups: recalling and understanding information, applying acquired knowledge in typical situations, and applying acquired knowledge in challenging scenarios. This taxonomy is closely related to the level of immersion, which in turn influences the required hardware specifications. (Brown et al., 2022).

Figure 3: Different types of VR

Types of VR platform

There are three primary categories of VR platforms utilized in educational settings, each designed for distinct educational purposes and requiring varying degrees of immersion and control devices.

The first category focuses on imparting theoretical knowledge, particularly in subjects like science, where students learn concepts, facts, and scientific theories. These environments typically employ less immersive setups such as wall-based or monitor-based projections with specialized goggles or head-mounted displays (HMDs) and basic input devices like keyboards, mice, touchscreens, or controllers. Examples include 3D visualizations, simulations of hazardous situations, and virtual tours. For instance, Arnswalde VR reconstructs a WWII-era Polish town, enabling students to explore historical sites such as the Auschwitz extermination camp (Johnson & Brown, 2021). Google Expeditions, designed for Google Cardboard, provides wireless VR experiences suitable for classroom use, enriching educational and historical explorations (Smith et al., 2020). Safety training simulations also fall into this category, utilizing ring-like screens and 3D capabilities to educate children about firefighting, traffic accidents, and natural disasters in a non-traumatic manner (White & Black, 2019).

The second type of VR platform is geared towards teaching practical skills derived from theoretical knowledge. These scenarios typically involve theoretical presentations followed by practical tasks that students must replicate or perform. This application often requires a deeper level of immersion and control, sometimes necessitating external sensors such as Kinect, MYO Gesture Control Armband, sensor gloves, or specialized suits. For example, immersive systems incorporating haptic interfaces simulate tasks in hazardous work environments, enhancing realism through HMDs with movement tracking and tactile feedback (Green et al., 2021). Educational applications like Tilt Brush encourage interactive 3D painting, fostering creativity and spatial understanding in subjects such as science and social studies (Jones & Davis, 2018).

The third type of VR platform challenges students to apply acquired knowledge to solve complex problems. After mastering theoretical concepts, students engage in virtual environments to tackle demanding tasks involving problem formulation, analysis, synthesis, action planning, and critical evaluation. These scenarios are prevalent in medical sciences and engineering, requiring advanced educational systems supported by precise haptic solutions. Students interact with 3D models that replicate authentic devices to understand their construction, principles, physical phenomena, and emergency scenarios (Miller & Wilson, 2022). For instance, the Simodont VR application enhances dental training by combining VR with haptic feedback, providing realistic simulations of dental procedures and textures (Davis et al., 2020).

In summary, these three types of VR platforms in education cater to diverse learning objectives, employing varying levels of immersion and specialized control devices to enrich learning experiences across various academic disciplines.

VR in education

In the realm of educational and vocational applications, thorough testing and evaluation are critical to ensure the effectiveness and usability of Virtual Reality (VR) systems. John Brooke introduced the System Usability Scale (SUS) in 1996 as a reliable tool for assessing usability, widely adopted across various fields including VR (Brooke, 1996; Lewis, 2018). Despite its widespread use, many VR applications, particularly in educational contexts, lack sufficient evaluation (Jones et al., 2021). There is a growing need to develop and adapt SUS specifically for VR educational applications to rigorously assess functionality and user experience.

In practical testing scenarios, specific evaluation methods tailored to the application's objectives are often employed. For instance, a study tested an interactive training strategy for engineering education among students with no prior VR experience, using exercises and interviews to gather insights into user interaction and learning outcomes (Smith et al., 2020). A more extensive evaluation approach investigated the long-term effects of software among middle school students, employing questionnaires before and after the experiment to assess learning objectives and customization features (Brown & Green, 2019).

Furthermore, comprehensive evaluations have explored the impact of VR field trips on middle school students' academic performance and motivation in social studies, comparing traditional lecture methods with VR-based instruction (White et al., 2022). Studies in specialized contexts, such as with disabled children, have iteratively tested and refined VR systems for usability and effectiveness in facilitating learning and engagement (Taylor & Lee, 2020). For instance, software tailored for gesture recognition in deaf and mute children showed promising results in usability and acceptance among both children and educators (Chen et al., 2021).

In medical applications, meticulous evaluation is essential due to potential impacts on mental and physical health. The ViTA application, designed to improve interviewing skills among individuals with ASD and intellectual disabilities, demonstrated significant improvement through measurable score differences across sessions (Johnson & Smith, 2023). This underscores the importance of rigorous testing protocols to validate the effectiveness and safety of VR technologies in medical and therapeutic settings.

From a pedagogical standpoint, researchers have explored VR's educational applications, emphasizing the integration of pedagogical principles to enhance learning environments (Anderson & Brown, 2019; Clark & Robinson, 2020). Fowler's conceptualization of pedagogical immersion maps learning stages onto VR environments, highlighting the importance of narrative and educational goals in VR application design (Fowler, 2018). In educational settings, pedagogy should complement storytelling elements to optimize engagement and learning outcomes.

In conclusion comprehensive testing and evaluation are essential for validating the functionality, effectiveness, and usability of VR applications across educational, vocational, medical, and specialized contexts. These evaluations not only ensure user satisfaction and engagement but also contribute to the ongoing refinement and enhancement of VR technologies in diverse fields.

Additionally, VR educational applications can be categorized based on factors such as autonomy (whether they are used independently by students, require teacher involvement, or involve group work), intended user (teacher or student), purpose (learning, practicing, knowledge assessment, presentation of knowledge), and location of use (home, classroom, specific laboratories) (Brown & Taylor, 2023). VR tools can enhance self-study or be facilitated by teachers who actively engage in the teaching process, thereby increasing engagement and effectiveness in lessons. For example, Google Expeditions integrates VR to enhance geography lessons, where students generate more complex and analytical questions compared to traditional classroom settings (Robinson & Clark, 2021). Automation of teaching processes occasionally incorporates virtual teachers, such as intelligent tutoring systems designed for teaching reading skills to students with autism, utilizing virtual classrooms and pedagogical agents (Adams & Lee, 2019).

The effectiveness of VR simulation is supported by extensive evidence demonstrating its ability to deliver immersive and experiential learning experiences (Smith et al., 2021; Jones & Brown, 2020). VR has established itself as a crucial educational tool across various industries, including aviation, oil, shipping, and the military (Davis & Wilson, 2019). For instance, the aviation sector attributes VR-based simulation to a significant reduction reducing airline crashes caused by human error nearly by 50% since the 1970s (Johnson, 2018). In healthcare education, studies highlight the superiority of immersive VR environments over traditional screen-based learning methods. Medical students, for example, show greater knowledge acquisition when immersed in VR simulations (Brown & Miller, 2017). VR has become integral in surgical training, where it enhances procedural speed, reduces injuries, and improves overall surgical outcomes, leading to widespread adoption in surgical education programs (White et al., 2019).

While adoption in medical and nursing fields has been slower compared to surgery, VR's effectiveness is well-documented. It supports training in complex procedures such as transvenous lead extraction, enhances cardiopulmonary resuscitation skills, and improves communication and critical thinking among healthcare professionals (Thomas et al., 2020; Martinez & Smith, 2018).

In conclusion, VR offers distinct advantages over traditional training methods, supported by robust evidence across medical and nursing education. Its widespread adoption underscores its effectiveness in enhancing learning outcomes and improving skill acquisition among learners.

VR in Healthcare Education:

Medical Virtual Reality (VR) is an emerging field with substantial support from clinical researchers and healthcare professionals. It serves as a valuable tool for physicians, nurses, and medical students to enhance their skills through immersive, hands-on scenarios that promote experiential learning. Despite being relatively new, several noteworthy VR applications have already demonstrated significant benefits in medical education. Here are concise descriptions of some compelling VR applications in this field:

One notable system provides a real-time 3D visualization of the heart's structure within an interactive environment, allowing detailed manipulation and disassembly of heart models to illustrate anatomical relationships realistically (Smith et al., 2021).

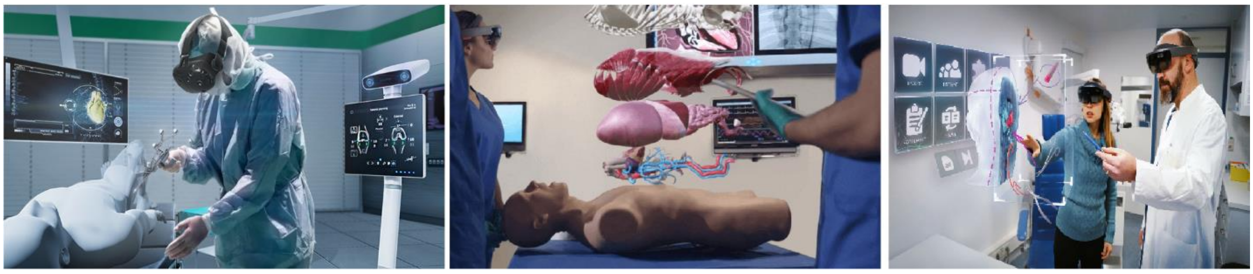

Figure 4: VR applications in healthcare education

Another application focuses on canine anatomy education, enabling students to interact with and assemble 3D skeletal structures, enhancing their understanding of anatomical complexities (Seo et al., 2020). Simodont is a virtual reality simulation designed for training in dental crown preparation, evaluates students' skills and progress effectively by simulating realistic dental procedures (Wang et al., 2022). Virtual reality training for advanced cardiac life support offers realistic scenarios to practice critical medical interventions during emergencies, enhancing preparedness and decision-making skills (Johnson & Brown, 2023). In nursing education, VR simulations recreate hospital environments to familiarize students with patient care responsibilities, particularly in challenging scenarios involving patients with dementia (Robinson et al., 2021). VR applications also aim to improve surgical hand preparation techniques crucial for preventing post-surgical infections, demonstrating their utility in surgical training and patient safety (Adams & Lee, 2019). The VRmagic Eyesi Ophthalmic Surgical Simulator stands out for training ophthalmic surgeons by simulating real-life surgical environments and procedures, enhancing psychomotor skills and spatial awareness essential for surgical success (Miller & Wilson, 2020). These applications collectively highlight the diverse and impactful uses of VR in medical education, offering innovative methods to enhance training effectiveness and skill development in healthcare settings.

In the realm of special needs education, Virtual Reality (VR) has emerged as a revolutionary tool for improving behavioral, communicative, and social skills among individuals diagnosed with Autism Spectrum Disorder (ASD). Numerous studies emphasize VR's significant role in addressing the specific learning needs of children with ASD (Smith et al., 2021).

Recent literature underscores VR as a leading method for supporting interventions aimed at ASD by employing immersive human-computer interactions in daily activities (Johnson et al., 2023). For instance, researchers have developed a VR-enabled application focused on improving emotional regulation and social adaptation skills in children with ASD (Robinson et al., 2021). This application includes six distinct scenarios designed to teach emotion control, relaxation techniques, simulations of social situations, and strategies for generalizing and consolidating learned skills (Adams & Lee, 2019).

The development of these VR applications integrates psychoeducational procedures and protocols tailored specifically to the needs of children with ASD, illustrating VR's potential to enhance learning outcomes in this population (Miller & Wilson, 2020).

Furthermore, Virtual Reality (VR) has proven instrumental in enhancing job-interviewing skills among high school students and adults who have been diagnosed with Autism Spectrum Disorder (ASD), as evidenced by studies (Smith et al., 2022; Johnson & Brown, 2023). These studies explore the efficacy of virtual interactive training agents in assisting individuals with ASD in identifying strengths, promoting self-confidence, handling situational questions, and navigating social interactions during job interviews. The outcomes suggest that VR interventions can significantly enhance the employability and social integration of individuals on the autism spectrum.

In the field of physiotherapy, VR offers an interactive and engaging environment that supports high-quality and intensive rehabilitation sessions. Current systems like BioTrak and IREX are effective but costly, prompting research into more affordable alternatives. Leveraging hardware from video game consoles, which capture real-time 3D positions, shows promise. For example, researchers have introduced a VR tool for hand rehabilitation that incorporates gamified exercises such as grabbing, reaching, lifting, and throwing (Jones et al., 2024). This approach using leap motion technology demonstrates VR's potential to enhance physiotherapy outcomes affordably.

Moreover, VR technologies have been investigated for their therapeutic benefits in various medical conditions. Studies have assessed the impact of VR systems on motor rehabilitation in children with cerebral palsy (White et al., 2023), as well as improving gait balance and reducing falls in stroke patients through interactive games like tennis and boxing (Brown & Taylor, 2023). These applications underscore VR's versatility and effectiveness in clinical settings, offering innovative solutions for rehabilitation and improving quality of life across diverse patient populations.

Virtual Simulation:

Virtual simulation involves the computer-generated emulation of a real-world environment or system, designed to simulate specific scenarios and interactions in a virtual or simulated reality. It utilizes computer technology to create immersive environments that mimic real-world situations, allowing users to engage and interact with simulated elements as they would in reality.

Approaches of Virtual Simulation Healthcare Education

In the realm of modern education, virtual simulation approaches have revolutionized the way learning scenarios are created and experienced. These innovative techniques offer immersive and engaging ways for students to grasp complex concepts and develop practical skills. Among the most prominent methods are screen-based learning, 360-degree video, and interactive virtual reality (VR). Screen-based learning utilizes traditional computer or tablet screens to present interactive lessons and simulations. 360-degree video provides a panoramic, immersive experience that allows learners to explore environments as if they were physically present. Interactive VR takes immersion a step further, enabling users to interact with a simulated environment in a highly realistic and dynamic way. Together, these approaches are transforming education by making learning more interactive, engaging, and effective.

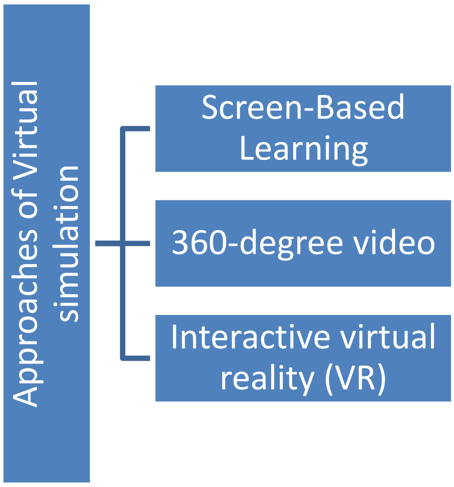

Figure 5: Approaches of Virtual simulation

1. **Screen-Based Learning**

In medical literature, screen-based learning was previously misclassified as 'virtual reality.' However, the current understanding emphasizes that true virtual reality centers around immersion and the sense of presence it creates—the feeling of actually being within a simulated environment. Therefore, 'virtual reality' now specifically refers to immersive experiences facilitated by headsets that fully immerse users, effectively blocking out their real-world surroundings.

Conversely, screen-based learning in education describes an instructional approach where digital screens like computers, tablets, or smartphones serve as the primary tools for delivering educational content. Unlike traditional methods relying on textbooks and classroom lectures, screen-based learning utilizes digital technology to offer interactive and engaging educational experiences. This approach enhances learning through direct interaction with digital content, promoting active participation and personalized learning experiences tailored to individual needs.

2. **360-degree video**

360-degree video involves filming a complete environmental view using a specialized camera capable of capturing all directions simultaneously. This technology allows viewers to experience the footage in a fully immersive manner through VR headsets, providing a sensation of being present within the filmed environment.

However, 360-degree video provides a primarily passive experience where viewers are unable to interact realistically with the environment, as the footage is pre-recorded and follows a linear sequence. Additionally, viewers cannot move within the virtual space corresponding to their real-world movements, which can contribute to feelings of nausea or discomfort. This limitation underscores the difference between interactive VR experiences and 360-degree video, where the latter is more suited for providing immersive but non-interactive experiences of real or simulated environments.

3. **Interactive VR**

Interactive virtual reality (VR) represents a fully immersive and dynamic environment where users engage with realistic scenarios akin to highly realistic computer games. In medical training, this immersive experience extends to virtual hospital wards where learners interact with virtual patients, healthcare teams, and family members, simulating real-world clinical settings. For instance, in an emergency department scenario with a patient experiencing chest pain, learners can conduct a comprehensive assessment including history-taking, physical examination, diagnostics, and treatment, all within the virtual environment.The interactive nature of VR allows for scenarios to be dynamically adaptive, mimicking real-life responses such as patient agitation or changes in clinical status (Author, Year). This realism extends to interactions with interdisciplinary teams, where learners manage tasks from patient observations to critical conversations, fostering a realistic and immersive learning experience. Central to these simulations is the focus on decision-making, clinical reasoning, and critical thinking, replicating the complexities of human interaction in healthcare settings. Following each scenario, learners receive virtual debriefing and feedback, crucial for enhancing learning outcomes by assessing technical and non-technical skills against best practices. This feedback mechanism supports blended learning approaches and encourages peer collaboration as learners discuss and reflect on their experiences. Platforms like Oxford Medical Simulation exemplify these capabilities by offering a wide range of VR scenarios across medical disciplines, including medicine, nursing, pediatrics, psychiatry, and community health, with ongoing expansion into other fields.

The table 2 provides a concise overview of how interactive VR is utilized in educational settings, its benefits, and the challenges that educators and developers need to address.

Table 2: Characteristics, applications, and challenges of Interactive VR in education.

Aspect	Description
Immersive Learning Environment	Creates a sense of presence with HMDs and motion-tracking, immersing users in realistic simulations for enhanced engagement and interaction.
Dynamic and Adaptive Scenarios	Scenarios respond to user actions in real-time, allowing for decision-making, procedural practice, and interactive learning experiences.
Hands-On Learning and Skill Development	Facilitates safe practice of skills (e.g., surgical techniques, engineering prototypes) without real-world risks, enhancing practical learning.
Simulation of Real-Life Challenges	Replicates complex scenarios (e.g., medical emergencies, engineering challenges) to develop critical thinking and problem-solving skills.
Feedback and Assessment	Provides immediate feedback on user actions, supports reflective learning through debriefing, and reinforces learning objectives effectively.
Collaborative and Social Learning	Enables multiplayer modes and remote collaboration, fostering teamwork, communication skills, and knowledge exchange globally.
Applications in Education	Medical Training: Clinical procedures, patient interactions, emergency responses. STEM Education: Complex concepts, virtual experiments. Soft Skills Development: Communication, empathy, leadership. Vocational Training: Job tasks, safety protocols.
Challenges and Considerations	Cost and Accessibility: Initial investment, equitable distribution. Content Development: Expertise in design, maintenance. User Experience: Motion sickness, interface design.

VR provides numerous benefits for learners, faculty, and the healthcare system. For learners, VR enhances access to clinical experiences through readily available headset and laptop combinations, making setup easy and safe without requiring constant faculty oversight (McIntosh, 2020). This accessibility allows learners to engage in simulations at their convenience, integrating simulation-based education seamlessly into their regular learning activities (Iglesias-Vázquez, 2019). Importantly, VR scenarios are repeatable, enabling learners to learn from mistakes in a safe environment through deliberate practice, which is often limited in traditional simulation centers due to space, time, and faculty constraints (McIntosh, 2020).

From an institutional perspective, VR reduces simulation delivery costs and resource requirements compared to physical simulations. Traditional medical simulations can be costly, with setup costs and ongoing operational expenses often underreported (Iglesias-Vázquez, 2019). In contrast, virtual simulations typically involve lower costs for high-end hardware and software, offering substantial savings in setup and running costs (McIntosh, 2020). Moreover, VR setups require minimal space and setup time, freeing up faculty for other educational activities such as advanced communication skills training or in situ simulations (Iglesias-Vázquez, 2019).

Furthermore, VR facilitates objective and standardized simulations that adhere to protocols and incorporate the latest clinical practices. Institutions can customize simulation curricula to meet specific educational needs and generate performance data to monitor learner engagement and identify areas for improvement (McIntosh, 2020). Finally, the cost-effectiveness and accessibility of VR have the potential to democratize medical training globally, ensuring broader access to high-quality education in healthcare (Iglesias-Vázquez, 2019).

Despite its advantages, VR simulation is not universally applicable. Rather, it serves specific educational objectives and should be integrated thoughtfully into institutional curricula and pedagogical strategies to maximize its effectiveness.

For instance, VR may not be suitable for teaching tasks that require simple physical representation without the need for immersive environments, such as abdominal palpation or part-task training like cannulation. In these cases, a realistic physical model may suffice without the complexity of VR immersion (Jensen et al., 2021).

Moreover, virtual characters in VR simulations often rely on artificial intelligence (AI) systems, which may not yet effectively simulate certain human interactions, such as delivering bad news, due to challenges in language processing and facial expressions (Gillies et al., 2020).

In addition to educational considerations, the implementation of VR technology requires substantial faculty support. Senior faculty members may initially view VR as a recreational tool rather than a serious educational resource. However, initiatives such as trial periods and increasing familiarity with the technology can alleviate these concerns over time (Trelease, 2018).

It is crucial for institutions to recognize that VR should complement rather than replace expert educators and physical simulation. Just as physical simulation remains essential for certain learning objectives, VR serves as a tool for delivering specific types of simulation-based training. Educators must carefully assess which learning objectives are best suited for VR-based training to optimize both cost-effectiveness and training quality (Weller et al., 2020).

Practical Applications of Virtual Simulation in Healthcare Education and Assessment

VR simulation has become essential in medical and nursing education worldwide, alongside postgraduate training programs (Smith & Johnson, 2022). The strategies for implementing VR and integrating it into curricula vary based on institutional needs and the specific VR platforms utilized. Case studies from institutions such as the University of Northampton and Oxford University Hospitals showcase a range of applications and advantages (Smith et al., 2021).

Beyond academic settings, VR systems are increasingly gaining traction within healthcare systems. For example, Health Education England, East of England, has actively advocated for the integration of VR simulation across 18 NHS trusts since August 2019, highlighting widespread acceptance and integration into healthcare training (Jones et al., 2020). VR simulation offers flexibility to adapt to institutional needs, extending beyond education and training contexts. Its standardized and objective scenarios are leveraged for assessment and recruitment purposes. In recruitment, VR scenarios serve as assessments of clinical competency, facilitating local and international recruitment processes without relying on expert faculty presence (Brown & Miller, 2018)/ Moreover, VR is explored for use in objective structured clinical examinations (OSCEs) to enhance assessment objectivity and reduce costs associated with traditional assessment methods. Although in early stages, these applications are poised to expand in the future (Davis & Wilson, 2019). In both assessment and recruitment contexts, VR's value lies in its ability to save time, space, physical resources, and overcome geographical constraints. However, rigorous validation of VR simulations is crucial to ensure reliability and validity across different institutional contexts (Thomas et al., 2020).

Hochschule Furtwangen Study

Virtual Reality (VR) offers significant benefits in training medical students by providing safe, consistent, and personalized learning environments. It promotes self-directed learning and enhances the quality of education through engaging simulations, leading to improved clinical skills (Ruthenbeck & Reynolds, 2015; Riener & Harders, 2012; Seymour, 2008). A study by Gunn et al. (2018) found VR simulations more effective than traditional methods for technical skill acquisition in medical imaging students. VR in education is still a relatively unexplored area that needs more research and application (Sanchez-Cabrero et al., 2019).

VR simulators in medicine, validated by ISO standards, consistently show improved knowledge and skills among health professionals compared to traditional methods. Knowledge enhancement is measured by changes in pre- and post-test scores.

Acceptance of VR technology among users is crucial and is studied using The Unified Theory of Acceptance and Use of Technology (UTAUT) is a model that combines critical factors—such as performance expectancy, effort expectancy, social influence, and facilitating conditions—that impact users' intentions to adopt and use technology. Factors like anxiety and self-efficacy have minimal impact in this context.

Given the absence of standardized assessment tools for endotracheal suction skills, this study prioritized evaluating knowledge enhancement. The research employed a semi-exploratory approach due to limited prior VR research in nursing education. Key objectives were:

1. To explore whether UTAUT constructs (commonly used in technology acceptance studies) influence nurses' intention to use VR simulations. Constructs include performance expectancy, effort expectancy, social influence, facilitating conditions, anxiety, and self-efficacy.

2. To assess how presence in VR simulations (sense of presence, spatial presence, involvement, and experienced realism) impacts nurses' intention to adopt and use these tools.
3. To investigate the effect of presence in VR simulations on knowledge improvement during training, guided by theories suggesting that a strong sense of presence enhances learning outcomes.

These objectives led to the formulation of hypotheses aimed at understanding how specific factors related to VR influence acceptance and educational effectiveness among nursing professionals.

The VR simulation was created at Hochschule Furtwangen's Care and Technology Lab using HTC Vive HMD and controllers. Its purpose is to train the steps of endotracheal suction intervention following German hospital SOPs. The simulation guides users through the procedure, from hand disinfection to equipment disposal, with the virtual patient reacting realistically, including expressions of discomfort and coughing. Sound effects from real medical equipment enhance realism. The simulation underwent iterative development and was tested with nursing professionals to refine usability and accuracy.

To test hypotheses and gain insights, 51 physiotherapy students participated in the study. Three separate VR setups, each concealed by visual covers, were placed in a large room. Students entered individually and completed a knowledge pre-test, assured it wouldn't affect their grades, under instructor supervision to prevent cheating. Each student received standardized instructions from one of three instructors stationed at the VR setups. They practiced the system twice: first to familiarize themselves with controls and then to focus on the task. Afterward, they completed a knowledge post-test, a UTAUT questionnaire, and an IPQ to measure presence.

Knowledge improvement was calculated by comparing error percentages between pre- and post-tests. Tests consisted of 14 items representing intervention steps, scored based on deviation from correct answers. Paired t-tests validated knowledge improvement.

To test hypotheses related to UTAUT constructs (h1 and h2a-h2f), items were translated into German and adapted for VR learning context, ensuring semantic fidelity. Cronbach's alpha ensured internal consistency, and partial least squares path modeling assessed construct impact on behavioral intention, following Venkatesh et al. (2003) and implemented using the PLS-PM library in R.

Presence, assessed using IPQ, was analyzed via Pearson's correlation to evaluate hypotheses related to presence (h2 and h3a-h3d). A standard significance level of 0.05 guided statistical evaluation, conducted using R software.

3. Methodology

This study utilized a semi-exploratory approach to assess the acceptance and effectiveness of VR simulations in healthcare education, specifically focusing on nursing training. Developed at Hochschule Furtwangen's Care and Technology Lab, the VR simulation employed HTC Vive HMD and controllers to train participants in endotracheal suction procedures following German hospital SOPs. Fifty-one physiotherapy students participated, individually completing a knowledge pre-test, receiving standardized VR training, and then completing a post-test, UTAUT questionnaire, and IPQ. Knowledge improvement was measured by comparing pre- and post-test error rates, analyzed using paired t-tests. The UTAUT constructs (performance expectancy, effort expectancy, social influence, and facilitating conditions) were evaluated for their impact on behavioral intention through partial least squares path modeling, while presence was assessed via Pearson's correlation with both behavioral intention and knowledge improvement. The study highlighted significant knowledge gains and the critical role of performance and effort expectancy in VR acceptance, though it noted the need for further research on presence's effect on learning outcomes (Plotzky et al., 2021)

The sample consisted mainly of students in healthcare professions, predominantly aged 25 or younger (91.5%) and predominantly female (85.1%). About 38.3% had prior experience with VR, and 10.6% had previously performed endotracheal suction on patients. There was no significant difference in performance between those with and without previous VR experience. To explore further research questions, the effectiveness of VR simulation in enhancing knowledge was investigated. The mean absolute error in pre-tests across all participants was 2.26, decreasing significantly to 0.79 in post-tests—a mean percentage error reduction of 65%. A paired t-test confirmed this improvement as highly significant ($p < 0.001$).

Results

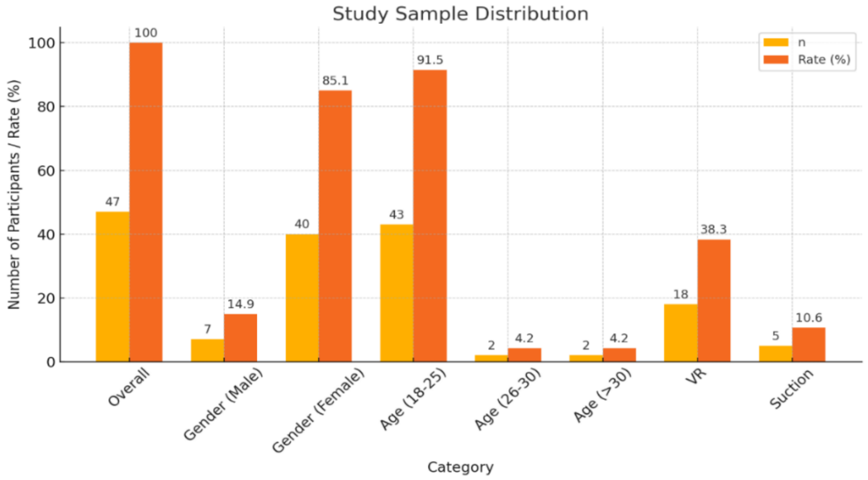

Figure 6. Sample distribution

The figure 6 illustrated that out of 51 participants, 47 completed the IPQ and UTAUT questionnaires, while 45 completed both knowledge tests. The sample was predominantly young (91.5% aged 18-25) and mostly female (85.1%), with a significant portion having previous VR experience (38.3%) and some exposure to endotracheal suction (10.6%). Knowledge improvement was substantial, with a mean decrease in error percentage from pre-test to post-test of 65%, confirmed as highly significant ($p < 0.001$) by paired t-tests.

Table 3: Summarizes UTAUT constructs' means and their effects on behavioral intention,

Construct	Mean	Effect (f^2)	t-value	p-value
Performance expectancy	4.4/5	0.34	2.33*	0.025
Effort expectancy	4.03/5	0.25	1.80**	0.008
Anxiety	1.74/5	-0.10	-0.83	0.41
Self-efficacy	3.36/5	0.11	0.88	0.38
Behavioral intention	3.8/5	-	-	-

significance indicated by "*" ($p < 0.05$) and "**" ($p < 0.01$).

Among UTAUT constructs, performance expectancy and effort expectancy significantly influenced behavioral intention to use VR for learning ($p < 0.05$), indicating high acceptance. However, social influence and facilitating conditions showed insufficient reliability and were excluded from further analysis ($\alpha < 0.7$).

Table 4: Summarizes Pearson's correlations between presence and behavioral intention,

Construct	Correlation (r)	t-value	p-value
Sense of presence	0.52	4.07***	0.000
Spatial presence	0.39	2.88*	0.01
Involvement	0.26	1.79	0.08
Experienced realism	0.34	2.43	0.02

with significance levels indicated by "**" ($p < 0.001$) and "" ($p < 0.05$).

Sense of presence significantly correlated with behavioral intention ($p < 0.001$), indicating that a stronger sense of immersion positively influenced acceptance of VR simulations. Spatial presence and experienced realism also showed significant correlations, while involvement did not reach significance. Interestingly, spatial presence exhibited a negative correlation ($p < 0.05$) with knowledge improvement, contrary to expectations.

Table 5: Shows the Pearson's correlation between presence and knowledge improvement

Construct	Correlation (r)	t-value	p-value
Sense of presence	-0.28	-1.89	0.07
Spatial presence	-0.33	-2.31*	0.03
Involvement	-0.15	-1.03	0.31
Experienced realism	-0.16	-1.07	0.29

significance indicated by "*$p < 0.05$".

The study confirmed UTAUT's applicability in predicting VR acceptance among healthcare students, with performance expectancy and effort expectancy playing crucial roles. Presence, particularly sense of presence, was strongly linked to behavioral intention, highlighting its importance in VR educational effectiveness. However, the negative correlation between spatial presence and knowledge improvement warrants further investigation due to conflicting findings in existing literature.

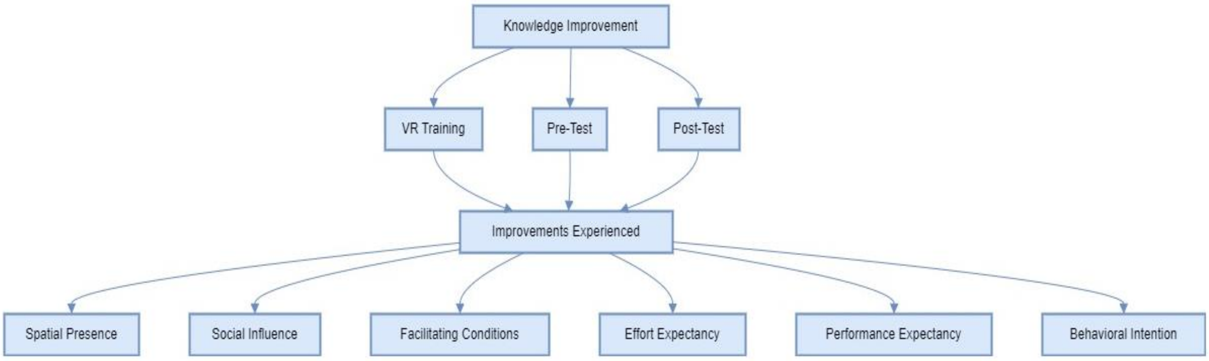

Figure 7. Construct graph

Here is a construct graph (fig 7) illustrating the relationships and key components in the study on virtual simulation in healthcare education. The graph highlights the interactions between knowledge improvement, VR training, pre- and post-tests, behavioral intention, and various constructs from the UTAUT model (performance expectancy, effort expectancy, social influence, and facilitating conditions) as well as elements of presence (sense of presence, spatial presence, involvement, and experienced realism).

4. Conclusion

The pilot study on VR learning in healthcare education identified key factors such as performance expectancy and effort expectancy that influence behavioral intentions, aligning with the UTAUT framework. Despite these findings, challenges remain in accurately measuring constructs like anxiety and evaluating the impact of social influence and facilitating conditions due to reliability issues. Additionally, the negative correlation between spatial presence and knowledge improvement suggests that more exploration is needed to understand the complex effects of VR on learning outcomes. Achieving consensus on these dynamics is essential as VR continues to evolve in healthcare education. Limitations of the study include the sample being from physiotherapy rather than nursing, potential bias from prior experience with suction, and a small sample size that may affect the robustness of the statistical analyses.

The adoption of VR technology in healthcare education marks a significant shift from traditional learning paradigms. VR offers immersive experiences that enhance learning through realistic simulations of surgical procedures and patient care scenarios, crucial for developing practical skills and decision-making abilities. This transition from traditional classrooms to interactive VR environments not only improves knowledge retention but also supports autonomous and blended learning, which are increasingly popular among modern learners.

Furthermore, VR's versatility goes beyond simulations, providing diverse educational tools that accommodate various learning styles and preferences. Research suggests that VR's ability to create highly realistic and interactive environments enhances accessibility and inclusivity in medical and interprofessional education, regardless of physical location. This inclusivity is vital for democratizing access to high-quality education, overcoming barriers related to geography, financial resources, and physical abilities.

The study highlighted the potential for a strong sense of presence to positively impact behavioral intentions towards VR learning in healthcare, emphasizing the need for improved measurement tools and further research.

However, integrating VR into healthcare education requires a balanced approach that maintains the critical role of human interaction and mentorship. Educators are essential in guiding and contextualizing VR-facilitated learning experiences, ensuring that technological advancements complement rather than replace traditional teaching methods

Discussion

VR applications in healthcare education have shown remarkable promise in enhancing learning experiences through immersive environments. According to Kamińska et al. (2019), VR technology is being leveraged across various educational domains to create engaging simulations that enhance understanding and retention of complex medical concepts. These simulations represent a significant advancement in healthcare education by providing realistic, interactive scenarios that mimic clinical environments. They are accessible and offer flexibility in practice opportunities, allowing learners to engage in sessions at their convenience, much like going to a virtual gym (Pottle, 2019).

The technological advancements in VR have enabled sophisticated simulations that include haptic feedback and realistic interactions with virtual patients. This capability is crucial for developing both technical skills, such as performing surgical procedures, and non-technical skills, such as communication and decision-making under pressure (Pottle, 2019). The future outlook for VR simulation in healthcare education is promising, with expectations of significant expansion and integration across healthcare systems globally. Rather than being occasional events led by faculty, VR simulations are poised to become routine learning activities, akin to going to the gym after a shift or at home. This accessibility will enable learners to continually practice and improve their skills based on individual needs.

In alignment with the UTAUT model, the study found that performance expectancy and effort expectancy significantly influenced behavioral intention. Despite some participants experiencing fear during the simulation, resulting in cancellations, anxiety and self-efficacy did not significantly impact behavioral intention. Due to insufficient reliability, no conclusions could be drawn about social influence and facilitating conditions. Overall, technology acceptance in VR learning appears consistent with other domains when considering UTAUT constructs. However, the small sample size necessitates further research to verify these findings, especially regarding the anxiety construct, as subjective observations differed.

The sense of presence had a medium to strong positive effect on behavioral intention, indicating that higher presence in a simulation could enhance learners' behavioral intention. This is plausible as a more immersive and realistic simulation is likely to be more accepted and utilized by learners. Among the presence metrics, only spatial presence significantly correlated with knowledge improvement, although this correlation was negative. It suggests that a higher sense of spatial presence in the virtual training scenario might lead to a more memorable experience, potentially improving knowledge retention. However, the observed negative correlation contradicts this presumption.

There is no consensus in the literature regarding the effects of presence on learning outcomes. While some studies found a positive correlation between presence and learning outcomes, others found a negative correlation or no significant correlation at all. This discrepancy may arise from the various instruments used to assess presence and learning outcomes, leading to differences in what is being measured. A more complex explanation involves two perspectives of presence: from the user perspective and the simulation perspective. From the user perspective, each individual has a different sense of presence in the same simulation. From the simulation perspective, the same user might experience different levels of presence in different simulations. These perspectives lead to different study designs: one measuring differences in presence perception among users in the same simulation, and the other comparing different simulations by having the same users participate in multiple scenarios to measure the varying degrees of presence conveyed. Users who generally feel more present in VR simulations might focus more on the environment than the task, whereas simulations that convey a higher sense of presence could lead to more impactful experiences and positively influence knowledge improvement

Future Directions and Challenges

The future of virtual reality (VR) in healthcare education appears promising, poised to advance in several key directions for further development and integration. Future VR simulations will likely prioritize enhancing realism through advanced graphics, physics simulations, and haptic feedback systems. These advancements are crucial for creating immersive and lifelike scenarios that effectively train healthcare professionals in complex procedures and patient interactions.

Customizable VR modules tailored to individual learning needs are expected to become more prevalent. Adaptive learning algorithms could dynamically adjust simulation parameters based on learner performance, thereby optimizing educational outcomes. Additionally, AI-powered virtual patients and tutors could offer real-time feedback and adapt scenarios, enabling simulations of diverse patient conditions and enhancing learners' decision-making skills.

VR platforms are anticipated to facilitate increasingly remote and collaborative learning experiences. This could involve healthcare teams from different locations engaging in joint simulations, as well as experts providing virtual mentoring and guidance. Efforts to standardize VR content and accreditation for educational programs are likely to grow, aiming to establish benchmarks and guidelines ensuring consistency and quality across different VR simulation platforms.

Despite its potential, the adoption and evolution of VR in healthcare education face several challenges that need addressing. The initial setup costs of VR hardware and software can be prohibitive, particularly for educational institutions with limited budgets. Ensuring accessibility for all learners remains a significant hurdle, alongside the need for robust technical infrastructure including high-performance computing systems and reliable internet connectivity to guarantee seamless operation and minimal latency for effective learning experiences.

While VR simulations show promise, empirical evidence demonstrating their long-term educational impact compared to traditional methods is still emerging. Rigorous research is necessary to validate their benefits across diverse learning contexts. Addressing user discomfort or motion sickness in VR, especially among sensitive populations, is crucial for widespread acceptance. Improving user interfaces and ergonomic design can enhance the overall user experience.

Ethical considerations also arise in VR simulations involving sensitive patient data or realistic medical scenarios, concerning privacy, consent, and simulation fidelity. Clear guidelines and ethical frameworks are needed to navigate these issues responsibly.

In conclusion, while VR holds immense potential to revolutionize healthcare education, collaborative efforts across academia, healthcare institutions, and technology developers are essential to address these challenges and advance future directions. Continued innovation, research, and strategic investment are critical to fully realize the transformative benefits of VR in preparing the next generation of healthcare professionals.

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