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Innovation in Simulation: Using Augmented Reality and Artificial Intelligence for Human Centered Medical Education

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ABSTRACT

Simulation is evolving to include immersive technologies and artificial intelligence which provide adaptive, highly realistic and engaging learning experiences. These pedagogical tools will reshape the boundaries of simulation curriculum to provide educational experiences that foster unique scenarios beyond cardiac arrest and resuscitation skills training. For instance, extended reality simulations combined with artificial intelligence can provide challenging, humanities-based topics related to ethics, and enhance empathy through embodiment experiences, and navigate difficult conversations with compassion. In addition, unlike traditional mannikin based simulations, technology enhanced simulations have numerous advantages including asynchronous, highly adaptive learning experiences, that can be used in resource limited institutions and can conform to various cultures, languages, and customizable scenarios. This editorial explores the advantages of augmented reality and artificial intelligence simulation and shares a vision for a renewed focus on human-centered medical education.

Introduction: Simulation as a Global Imperative

Simulation is a cornerstone of medical education, transforming how healthcare providers learn to manage acute medical crises. Simulation technology has evolved over several decades to utilize not only high-fidelity mannequins but also fully immersive extended reality (XR) environments using head mounted displays (HMDs).[1] Today, artificial intelligence (AI) is redefining the boundaries of simulation, offering real-time, adaptive learning systems that are seamlessly interactive and deeply personalized.[2] Artificial intelligence-enhanced simulations provide scalable, on-demand role-playing that is conversationally close to human interactions. These systems enable asynchronous learning, allowing learners to immerse themselves in an array of clinical scenarios to develop clinical acumen at an individualized pace.[1]

While these technology advances enable scaling to resource-variable settings without simulation centers, a renewed focus is emerging: the need to re-center the human in clinical care.[3] Extended reality and AI are not just advanced pedagogical tools that promote knowledge acquisition and decision making, they also hold the potential to deepen empathy, ethics, and emotional intelligence. This editorial explores how immersive technologies can foster not only clinical competence, but renew the human connection in medicine.

Traditional Simulation: Strengths and Limitations

Traditional simulation remains an invaluable educational modality, offering opportunities to hone technical skills, practice team dynamics, and manage medical emergencies.[4] In addition to practicing crisis resource management and team dynamics principles in dedicated simulation centers, the mobility of in situ simulation has provided opportunities to enhance patient safety and workflow in the actual workplace setting including low acuity inpatient care wards and high acuity perioperative settings.[4] However, current modalities of simulation are not without limitations. High-fidelity mannequins and simulation centers require substantial infrastructure, ongoing maintenance, and a team of administrative and technically skilled staff, rendering them both limited and costly.[5] Organizing traditional simulations demands significant resources, including releasing medical trainees from patient care, coordinating instructor availability, reserving simulation center space, and coordinating standardized actors. [6] The audiovisual equipment needed to support monitoring and debriefing further adds to these challenges.[6] Moreover, in situ simulations require teams staff to be removed from patient care responsibilities that can place pressure on patient care and can be challenging for coordination and scheduling[6] These inherent limitations of mannikin-based simulation reduce scalability, particularly for geographically dispersed or time-constrained learners.[6] In addition, while traditional simulations aim to recreate clinical scenarios, they often lack the conveyance of emotional, cultural, and behavioral characteristics of real-world patient care.[7] In contrast, AI and XR technologies enable entry into immersive, dynamic, and accessible environments, enhancing not only technical proficiency but also humanistic competencies. As a result, these technologies may mitigate the barriers to traditional simulation and provide enhancements to current curriculum.

Augmented Reality: A Leap in Embodied Learning

Extended reality technologies using HMDs encompass 360-degree videos, virtual reality (VR), augmented reality (AR), and mixed reality (MR). These approaches differ in the ability to separate the natural and digital worlds, with MR representing dynamic integration of real-world environments and interactive holographic content.[8] Unlike VR, which immerses users in computer-generated settings, AR overlays holograms onto the real world, maintaining critical contextual cues such as spatial orientation, nonverbal feedback, and interpersonal communication among participants. While 360-degree video simulations

offer affordable, immersive perspectives of real life environments, they are less effective than AR in provoking physiological arousal and long term memory potentiation.[9-10] Augmented reality simulations elicit parasympathetic responses comparable to those in traditional in-person simulations, a physiological marker linked to enhanced learning.[10] In addition, AR simulations enable safe and repeatable high-risk scenarios that may be difficult to duplicate using traditional methods. By relying solely on internet connectivity and a HMD, AR simulations are portable and provide remote access, facilitating resource-agnostic, immersive learning opportunities.[11]

Artificial Intelligence Integration: Toward Adaptive and Human-Centered Simulations

Artificial intelligence is rapidly transforming immersive simulations by *dynamically adapting to learners' needs,* ensuring that students remain engaged. In an AR- and AI-integrated learning platform, the simulation can respond in real time and adapt based on the participants' actions, such as responding to participant gaze by utilizing eye tracking embedded in the HMD.[12] Artificial intelligence can also embed cultural and emotional intelligence into simulations, enabling AI-powered avatar patients to present culturally nuanced behaviors, language, and expressions.[13] Web-based AI learning platforms already exemplify these capabilities, providing multidirectional feedback between faculty and students, a feature particularly valuable in low-resource settings with limited dedicated simulation infrastructure. Extended reality simulations integrated with the functionalities of web-based AI platforms offer a scalable strategy to improve education for healthcare providers in any setting with internet connectivity.

Vision for the Future: Toward Deeper Learning and Humanism

The future lies not only in adopting new technologies, but in expanding the scope of medical simulation. While traditional simulation focuses on resuscitation, crisis resource management, and technical competency, these new technologies will help re-cultivate the humanistic side of medicine.[14] Immersive XR combined with AI offers a means to support emotionally responsive learning. In addition to training clinicians to manage sepsis or respond to cardiac arrest, simulation scenarios can be designed to address the humanistic skills that define exceptional care. By using holograms, voice recognition, and narratives that can adapt in real time, XR enhanced with AI simulations approach real-life conversations and emotional responses that are almost indistinguishable from human interactions.[15] By reducing the cognitive load required to imagine these interactions, instructors can guide learners through scenarios that were once difficult to teach. For instance, high fidelity XR AI enhanced simulations may serve to revitalize empathy and address vaccine hesitancy through honing communication and addressing misinformation.[16] Furthermore, immersive environments that respond dynamically to learner choices can simulate the delicate nuances of ethical decision-making and interpersonal communication, including how to convey poor outcomes, disclose medical errors, or navigate difficult conversations with compassion.[17] These tools also promote embodiment, allowing learners to experience patients' perspectives of pain, fear, or marginalization.[18]

Implementation Challenges and the Path Forward

Despite promise, significant barriers remain. Immersive technologies including XR and AI require robust infrastructure, technical training, and sustained investment.[19] Many healthcare systems, particularly in low- and resource-variable countries, may struggle to develop these tools without support. As healthcare providers who aim to ensure global equity, we must prioritize open-source development, cross-institutional collaboration, and research that serves a diverse, international population. Partnerships across international institutes are necessary to create learning platforms that are inclusive, broadly

accessible, and attuned to cultural and contextual differences. Additionally, rigorous, multi-center studies are needed to validate the effectiveness of these tools.

Conclusion: Technology in Service of Humanity

As we reflect on the current state of healthcare and look towards the future, one notion must guide us: technology should enhance, not replace, the human connection in medicine. Immersive simulation, empowered by XR and AI, should serve to deepen our empathy, improve our communication, and enhance ethical reasoning. We have the opportunity to shape simulation as a tool not only for learning crisis algorithms, but for human compassion to bring us closer together in a technological world. Extended reality powered by AI can power applications that speak every language, respect culture, and honor the shared humanity of caring for patients around the world.

Conflicts of Interest:

TJ Caruso is on the board of a nonprofit (Invincikids, Inc.), that seeks to distribute immersive technology to hospitalized children at no cost. He receives no direct or indirect compensation for this role. TC is a director of the Stanford Chariot Program, which has received philanthropic donations from Meta, Inc. and Magic Leap, Inc. A. Rama declares no conflicts of interests.

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