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Taking preclinical dental education to another level with mixed reality technology

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Extended reality (XR) tools have been widely adopted by educators in the health professions to enhance student learning experiences and improve surgical outcomes.^{1,2} XR is a broad term that encompasses a variety of technologies that blend digital and real-world elements. These tools can be categorized based on the extent to which digital and physical elements are integrated. Virtual reality (VR) is a fully digital environment, generated by computer simulations, while augmented reality (AR) overlays virtual content onto real-world settings through transparent head-mounted displays. Mixed reality (MR) merges both VR and AR, allowing users to simultaneously interact with both the physical world and digital elements, creating immersive environments.

In medical education, XR tools offer significant advantages, particularly when it comes to visualizing complex anatomical structures. By using 3-dimensional (3-D) models within virtual environments, students can explore anatomy in ways that were previously impossible with traditional methods. HoloLens, which is a mixed reality headset that leverages augmented reality to project digital information and holograms onto the user's physical environment was introduced by a software company (Microsoft, Redmond, WA, USA) in 2016.³ It functions as a hands-free computer, enabling users to seamlessly interact with both real-world and virtual objects at the same time (Fig. 1). The

HoloLens was quickly adapted for surgical planning, medical education, and patient education.

The field of dentistry has also embraced XR technologies for various educational purposes. XR has been employed to enhance head and neck education, assist in implant placement on phantom patients, aid in oral maxillofacial image-guided surgeries, and improve skills in local anesthesia administration. These applications are particularly valuable in simulating real-life procedures, allowing students to gain hands-on experience without the need for actual patients.

A notable example of XR technology in dental education is the "Jaws-in-Motion" project, developed in 2023 by the CWRU School of Dental Medicine in collaboration with Interactive Commons, which is an innovation institute to connect individuals from across our campus and our region through advanced visualization to further research and education. This innovative program, using HoloLens AR technology, was designed to accelerate the learning of vital head and neck structures. The interactive AR model features a dynamic 3-D skull with a movable mandible, which can be programmed to simulate various jaw movements, such as opening and closing, protrusion, and lateral excursions. This allows students to observe the position of the teeth in relation to the mandible's condyles and how these positions change during different functional movements. Furthermore, the model can simulate three types of glenoid

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Figure 1 Faculty and dental students wearing HoloLens during dental anatomy lecture.

fossa configurations (shallow, moderate, and steep) allowing students to visualize how the architecture of the fossa impacts condylar guidance and, in turn, affects dental occlusion and overall jaw mechanics.

For dental students, Head and Neck Anatomy courses are critical in their education, and supplementing these courses with AR technology not only deepens students' understanding of anatomical structures, but also accelerates their comprehension of how these structures influence functions such as jaw movement. Many first-year dental students have reported gaining a clearer understanding of the condylar and tooth positions in centric relation relative

to maximum intercuspation after using the Jaws-in-Motion program.

It has been suggested that XR tools such as HoloLens offering a dynamic, interactive environment provide a more comprehensive and effective learning experience, bridging the gap between theoretical knowledge and practical application.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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