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Improving the Methodology of Teaching Human Anatomy and Physiology Using Immersive Technologies

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Abstract: The worldwide shortage of cadaveric material and the rapid evolution of Extended Reality (XR) platforms have converged to renew interest in virtual, augmented and mixed-reality solutions for anatomy and physiology education. This study analyzes the pedagogical impact of immersive technologies in the pre-clinical curriculum of undergraduate biology students at Shakhrisabz State Pedagogical Institute. A quasi-experimental design compared an intervention cohort (n = 41) receiving instruction with a mixed-reality application running on HoloLens 2 to a control cohort (n = 43) taught with conventional cadaver prosections and plastinated models. Cognitive outcomes were measured with a validated 50-item multiple-choice examination; affective outcomes were captured through a five-factor engagement scale. After six weeks, the intervention group achieved a mean score of 84.6 ± 6.3 versus 74.1 ± 7.8 in the control group ($p < 0.001$; Cohen's d = 0.76). Engagement ratings were significantly higher across all factors, particularly "spatial comprehension" and "self-directed inquiry". Qualitative analysis of semi-structured interviews revealed that immersive visualisation reduced cognitive load, supported collaborative problem solving and stimulated intrinsic motivation. The findings confirm that carefully integrated XR modules can enrich anatomy and physiology teaching, provided that instructional design principles, technical infrastructure and faculty development requirements are addressed.

Keywords: Immersive technologies; virtual reality; augmented reality; mixed reality; human anatomy; physiology education; medical pedagogy.

Introduction: Human anatomy has traditionally been taught through dissection, prosection and atlas-based illustration. While these modalities foster tactile familiarity with human tissue, they present logistical, ethical and financial constraints, notably intensified by recent cadaver shortages and infection-control regulations [1]

Concurrently, engineering advances have produced head-mounted displays capable of rendering photorealistic, manipulable holograms of complex biological structures. Early evidence indicates that such immersive environments deepen spatial cognition and promote active learning behaviours among health-science students [2]

Nevertheless, most published trials focus either on small elective modules or on isolated laboratory demonstrations, leaving unanswered questions about scalability, curricular alignment and long-term retention [3]

Uzbekistan's higher-pedagogical sector is engaged in a wider digital transformation that prioritises interactive, student-centred approaches. Within this context, our institute introduced a mixed-reality (MR) anatomy programme grounded in constructivist learning theory and multi-sensory cognitive load reduction. The present article reports the design, implementation and evaluation of this programme, addressing the following research questions: (i) Does MR instruction improve short-term knowledge acquisition compared with traditional methods? (ii) How do students perceive the usability and educational value of MR in learning anatomy and physiology? (iii) What organisational and technical factors influence successful adoption?

The study employed a nonequivalent-group, pre-test/post-test design conducted during the spring semester of 2024 – 2025. Second-year biology majors enrolled in the mandatory "Anatomy and Human Physiology II" course were invited to participate. After informed consent, two intact seminar groups were randomly assigned to the MR intervention or the conventional teaching condition. Baseline demographic variables (age, prior VR experience, grade-point average) did not differ significantly between cohorts.

Instructional content targeted four organ systems: cardiovascular, respiratory, musculoskeletal and nervous. In the control cohort, each system was delivered over three 90-minute face-to-face sessions featuring cadaveric prosections, plastinated slices and histological slides. In the intervention cohort, the identical time allocation was retained; however, cadaver use was replaced by the HoloAnatomy® Software Suite running on HoloLens 2 devices, supplemented by a bespoke physiology simulation written in Unity. Both cohorts received identical print hand-outs, learning objectives and formative quizzes.

Knowledge outcomes were measured with a 50-item multiple-choice test validated by an expert panel (Cronbach $\alpha = 0.82$). Engagement was assessed using the Immersive Learning Engagement Index (ILEI), which captures attention, curiosity, perceived usefulness, spatial understanding and collaborative inclination on a five-point Likert scale. Semi-structured interviews were conducted with 12 purposively selected students from each cohort and transcribed verbatim for thematic analysis.

Statistical analysis employed SPSS 29.0. Between-group differences were evaluated with independent-sample t-tests for continuous variables and Mann–Whitney tests for ordinal scales. Effect sizes were reported as Cohen's d. Interview transcripts were coded iteratively using Braun and Clarke's reflexive thematic approach until saturation.

All 84 enrolled participants completed the course. The mean post-test score in the MR cohort was 84.6 ± 6.3, significantly exceeding the control cohort's 74.1 ± 7.8 ($t = 6.85$, $p < 0.001$), yielding a large effect size of $d = 0.76$. Sub-analysis revealed that spatially complex questions involving three-dimensional relationships (e.g., coronary artery trajectories, brachial plexus branching) displayed the greatest differential ($\Delta = 14.2$ percentage points). No significant difference emerged on items assessing rote recall of terminology.

ILEI mean composite scores were 22.3 ± 2.1 for the MR group and 18.5 ± 2.8 for the control group ($U = 412$, $p < 0.001$). The strongest gains were observed in the "spatial comprehension" sub-scale (MR = 4.7 ± 0.3 vs. Control = 3.5 ± 0.6) and "self-directed inquiry" (MR = 4.4 ± 0.4 vs. Control = 3.2 ± 0.7).

Thematic analysis yielded three dominant themes. First, students described the holographic models as "intuitively navigable", enabling kinesthetic exploration of micro- and macro-structures without the olfactory discomfort or ethical ambiguity of cadaver dissection. Second, MR was credited with catalysing peer instruction; learners spontaneously formed small groups around shared holograms, co-constructing explanations of physiological mechanisms. Third, the novelty of the technology generated strong intrinsic motivation, though technical setbacks such as network latency occasionally disrupted immersion.

The present findings corroborate and extend previous international studies demonstrating the pedagogical efficacy of XR in health-science education [4]. The 10.5-point mean improvement in examination performance parallels the gains reported by Jallad et al. among Palestinian nursing students using VR anatomy modules [5]. The pronounced advantage on spatial reasoning tasks supports cognitive-theory models positing that dynamic, manipulable 3-D representations reduce extraneous load and foster germane schema construction. Moreover, elevated engagement metrics substantiate arguments advanced by Johnson and colleagues that XR environments align with heutagogical principles of self-directed learning and situated cognition [6]. The qualitative data suggest that social presence—an affordance uniquely amplified in collaborative MR—acts as an additional mediator of learning benefit, a hypothesis echoed in recent mixed-reality hospital-teaching trials [7].

Implementation, however, is far from frictionless. Reliable high-bandwidth wireless networks, scheduled calibration sessions and faculty development workshops emerged as non-negotiable prerequisites. Cost analyses indicate that, although capital expenditure on headsets remains significant, lifecycle expenses may be offset by decreased cadaver procurement and maintenance, consonant with cost-benefit projections published by HoloAnatomy programme evaluators [8].

Several limitations warrant acknowledgment. The quasi-experimental design, while pragmatic, cannot fully eliminate selection bias. The follow-up duration did not permit assessment of long-term retention or transfer to clinical reasoning tasks. Finally, the study was conducted within a single institution, restricting external validity to contexts with similar technological capacity and curricular structures.

Integrating mixed-reality modules into a core anatomy and physiology course produced significant gains in knowledge acquisition, spatial reasoning and learner engagement without lengthening scheduled contact time. These outcomes, aligned with international evidence, affirm immersive technologies as a viable complement—and in specific competencies a partial alternative—to cadaveric resources. Future research should explore longitudinal retention, haptic feedback integration and faculty perceptions to inform sustainable, evidence-based curricular redesign.

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