

Academic Performance of Radiography Student Cohorts: A Comparative Study of Virtual Reality Intensity in Human Anatomy Education

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Abstract

This study evaluated how different intensities of virtual reality (VR) in human anatomy course affect radiography students' performance. Three distinct radiography student cohorts were compared: Cohort 1 (n=121) used traditional methods only; Cohort 2 (n=123) integrated 20 minutes of VR activity into four collaborative sessions in addition to traditional methods; and Cohort 3 (n=102) received six dedicated one-hour VR sessions in addition to traditional teaching. All cohorts followed the same curriculum, were taught by the same team, and completed final examinations based on an identical blueprint. Overall performance differed significantly ($p=0.025$). Only the intensive VR cohort outperformed the traditional cohort (80.35% vs. 77.31%, $p=0.013$), effectively raising the average grade from B+ to A- and increasing the proportion of A grades. These findings indicate that VR improves anatomy learning only when delivered with sufficient intensity, supporting its use as a structured supplementary tool to help students master complex 3D spatial relationships.

Keywords: Human Anatomy Education; Virtual Reality; Student Academic performance; Teaching Technologies.

1. Introduction

Human anatomy forms the foundation of healthcare education, providing the knowledge of structure and function required for clinical practice. Mastery of this subject is essential, as it supports accurate diagnosis, surgical precision, and effective communication among healthcare teams (Singh et al., 2019). A thorough understanding of anatomical relationships is also necessary to reduce medical errors and ensure safe patient care (Finn et al., 2018). For these

reasons, anatomy remains a core component of healthcare curricula, particularly in radiography where spatial awareness is critical.

Traditionally, anatomy was taught through memorization and cadaveric dissection (Dawson et al., 2009). However, institutions now face challenges such as high costs, ethical concerns, and limited laboratory access especially during pandemics like COVID-19 (Saverino, 2020). Additionally, traditional 2D diagrams often fail to support the translation of planar illustrations into a 3D understanding of anatomical relationships. This deficit in spatial perception makes the visualization of complex regions, such as neuroanatomy and cross-sectional anatomy, inherently difficult for many learners.

To address these challenges, Virtual Reality (VR) has been introduced as a practical teaching tool. VR allows students to interact with anatomical structures in a 3D environment (Zhao et al., 2020). Unlike passive learning methods, VR encourages active participation through simulated dissections, which can improve engagement, knowledge retention, and spatial understanding (Zhao et al., 2020). Two concepts help explain why the intensity of VR may matter. First, the task-technology fit perspective suggests that learning benefits are more likely when the capabilities of the technology match the demands of the learning task (Zhang et al., 2017). This is particularly relevant in radiography anatomy, where students must understand complex 3D spatial relationships. Second, cognitive load theory suggests that brief exposure to a new immersive tool may initially impose extra processing demands related to navigation and familiarization, which may limit immediate academic gains until students become more comfortable with the system (Sweller, 2011).

Despite VR having shown general benefits, its specific impact on sustained academic performance in subjects like human anatomy remains a subject of ongoing study. Some research shows improvements in test scores, while other studies suggest that VR may have a limited effect on final outcomes if not implemented in a sufficiently structured way. Moreover, most studies compare the presence or absence of VR rather than on the “dose” or intensity of exposure, leaving open the question of how much structured VR time is required to move beyond novelty effects and achieve measurable academic gains. In our published companion study involving the 2024/25 blended-VR cohort, students reported positive engagement and perceived learning benefits, although limited access time and technical constraints were also identified (Chiyanka et al., 2025). Therefore, this study evaluated how different intensities of VR integration into a human anatomy course affect academic performance by comparing academic outcomes across three sequential radiography cohorts.

2. Methods

2.1. Study Design and Setting

This quantitative comparative study analyzed three cohorts of radiography students: Cohort 1 (n=121), Cohort 2 (n=123), and Cohort 3 (n=102), enrolled in a first-year human anatomy course during the 2023/24, 2024/25 and 2025/26 academic years. Across these years, curriculum content, course outcomes, contact hours, and the assessment blueprint remained unchanged, and the same instructional team delivered all lectures and collaborative sessions. The study was approved by the institutional ethics committee (HSEARS20250409003).

2.2. Interventions

2.2.1. Traditional Learning Method

Cohort 1 (2023/24) used only traditional learning methods. Students received normal structured lectures and attended seven one-hour collaborative learning sessions (staggered throughout the 13-week semester) that were aligned with the lecture modules. During these sessions, lecture material revision was discussed, with an emphasis on the most important parts. Additionally, real-life case scenarios, mini presentations, and manikins were employed to consolidate theoretical knowledge and bridge the gap between theory and practical application. The remaining six sessions (six weeks) were reserved for individual consultations, allowing students to meet with the tutor optionally on a one-to-one basis, either face-to-face or online.

2.2.2. Blended Traditional and VR Learning

Cohort 2 (2024/25) utilized a blended learning approach that integrated traditional methods with VR technology. For this cohort, four of the seven one-hour collaborative learning sessions were aligned with specific curriculum modules: thorax, abdomen and pelvis, neuroanatomy, and musculoskeletal system. Within these four specific sessions, the traditional activities were condensed to allocate approximately 20 minutes of dedicated, group-based VR activities.

In these VR sessions, students were organized into groups of six. The VR experience was screen-cast so that all group members could observe the actions of the student wearing the VR headset. Each student used the VR set for approximately 10 minutes to minimize eye strain. Every group was given module-specific tasks and questions to complete within the VR system, as described in our previous publication (Chiyanika et al., 2025). These tasks involved hands-on interaction with 3D anatomical models, including manipulating and hiding structures to achieve specified views. Students also discussed the spatial relationships of anatomical structures to consolidate their understanding and reinforce key lecture outcomes.

The remaining portions of these sessions, as well as the other collaborative sessions and the six weeks of individual consultations, followed the same traditional format described for Cohort 1.

The total structured VR exposure to students for this cohort was approximately 80 minutes across the semester.

2.2.3. Intensive VR Integration and Traditional Methods

Cohort 3 (2025/26) implemented a comprehensive learning approach that included both traditional methods and an intensive, dedicated VR component. All seven one-hour collaborative learning sessions throughout the 13-week semester followed the traditional format described for Cohort 1, utilizing lecture revisions, case scenarios, and manikins to consolidate theoretical knowledge.

The VR intervention in this cohort was expanded by repurposing the six one-hour sessions previously reserved for individual consultations. These dedicated sessions were specifically aligned with the lecture modules. In these sessions, students worked in groups of six, receiving module-specific tasks and questions to complete within the VR system. Unlike Cohort 2, which used VR for only 20 minutes, Cohort 3 dedicated the full one-hour duration to VR-based activities as described in Cohort 2. This allowed more time for orientation, repeated practice, discussion, and clarification of complex structures. The aim was to use VR more intensively to support clinically relevant spatial reasoning and reinforce lecture outcomes without reducing the time allocated to traditional collaborative learning.

2.3. Student Performance Assessment

To ensure that student performance was not confounded by their university entry scores, the baseline university admission scores (any 5 best subjects) across cohorts were analyzed. We then compared the final human anatomy grades/scores across the three groups to evaluate the impact of each pedagogical approach. Grade distributions and mean scores were extracted from institutional records. The grading scale was defined as A+ (90–100%), A (85–89%), A- (80–84%), B+ (75–79%), B (70–74%), B- (65–69%), C+ (60–64%), C (55–59%), C- (50–54%), D+ (45–49%), D (40–44%), and F (0–39%).

All cohorts were assessed through group presentations, an individual take-home assignment, and a closed-book final examination of comparable format and difficulty, based on the same blueprint covering gross anatomy content relevant to radiography. Minor annual adjustments to individual items were made for security reasons, but the cognitive level and topic weighting were held constant. Since student engagement and perceived learning were not measured uniformly across all three cohorts, the present comparative analysis focused on institutional academic results only; these broader outcomes are discussed in relation to our published companion study of the blended-VR cohort (Chiyanika et al., 2025).

2.4. VR Safety

To ensure student well-being, several safety precautions were implemented during the VR sessions. Students were briefed on safe usage and the importance of breaks to prevent eye strain or motion sickness. The physical space was cleared of hazards, and students remained seated to prevent falls while peers viewed the session via a cast screen. Instructors monitored the sessions closely to provide technical support or assistance if students experienced discomfort. Anyone feeling dizziness or nausea was encouraged to stop immediately, ensuring a safe and supportive learning environment.

2.5. Data Management and Confidentiality

Data were managed per institutional ethics and protection guidelines. Academic records were anonymized, stripped of identifiers, and stored securely to ensure student privacy.

2.6. Statistical Analysis

Data analysis was conducted using SPSS (Version 28), with all tests being two-sided and a p -value < 0.05 considered statistically significant. Continuous variables, such as student scores, were expressed as mean $\pm$ standard deviation (SD), while categorical variables such as letter grades were expressed as frequencies (n) and percentages (%).

To compare continuous data across the three cohorts, a Welch ANOVA was employed to account for potential unequal variances, followed by Dunnett's T3 post-hoc tests for pairwise comparisons. For ordinal data, a Kruskal-Wallis H test was utilized to identify significant differences among groups, with Mann-Whitney U tests performed as post-hoc analyses to determine specific group differences.

3. Results

3.1. University Entry Results Analysis

A total of 346 first-year Radiography students studying Human Anatomy from three consecutive cohorts across the 2023–2025 academic years were evaluated. Baseline university admission scores across the cohorts were comparable ($p = 0.204$). Details are shown in Table 1.

Table 1. Showing the baseline University entry results among the cohorts

Academic Year	Weighted scores in 5 best subjects	P-value
Cohort 1, n=121	33.18±2.68	0.204
Cohort 2, n= 123	33.83 ±2.35	
Cohort 3, n= 102	33.73±3.76	

The Welch's ANOVA was used. Significance is $p < 0.05$. Cohort 1= traditional learning, Cohort 2= blended virtual reality learning, Cohort 3= intensive virtual reality intervention.

3.2. Overall Academic Scores of Student Cohorts in Human Anatomy

There was a significant difference in student scores among the groups ($p = 0.025$), with only the 'traditional learning cohort' being significantly different from the 'intensive VR intervention cohort' (77.31 ± 7.27 vs. 80.35 ± 8.32 , $p = 0.013$), an absolute increase of approximately 3%. No significant differences were observed between 'traditional learning cohort' and 'blended VR learning cohort' (77.31 ± 7.27 vs. 78.73 ± 9.11 , $p = 0.448$) or between 'blended VR learning cohort' and 'intensive VR intervention cohort' (78.73 ± 9.11 vs. 80.35 ± 8.32 , $p = 0.415$). The overall effect size for the ANOVA was Cohen's $f = 0.37$, which falls between medium and large according to Cohen's conventions, suggesting that the intensity of VR integration accounted for a substantial proportion of the variance in academic performance across the three groups.

3.3. Student Grade Distribution Across Cohorts

There was a significant increase in the percentage of students achieving an 'A' grade in the 'intensive VR intervention cohort' (23.5%) compared to 'blended VR learning cohort' (13%) and 'traditional learning cohort' (10.7%), $p = 0.027$. While the 'blended VR learning cohort' showed a higher frequency of 'A+' grades than 'traditional learning cohort' (14.6% vs. 5.8%), this trend was not statistically significant ($p = 0.060$). Overall, the data suggests an upward trend in higher grade attainment (A and A-) within the VR-integrated cohorts, particularly in the VR intensive cohort (Figure 1).

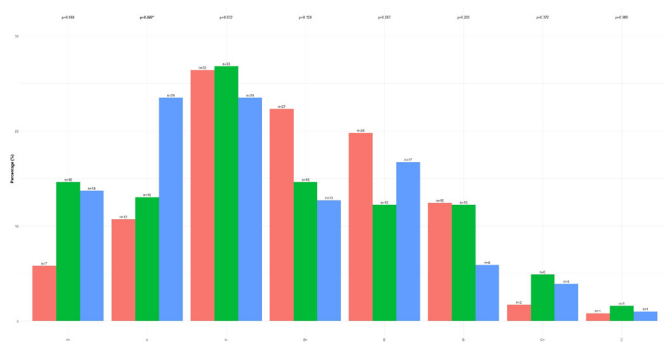


Figure 1. showing grade distribution across cohorts.

4. Discussions

This study demonstrates that while VR integration can improve student performance, intervention intensity is critical for achieving statistically significant gains. Despite comparable baseline scores, only Cohort 3 (intensive VR) significantly outperformed Cohort 1 (traditional learning), raising the average grade from a B+ to an A- and doubling 'A' grade attainment (23.5% vs. 10.7%). In contrast, the 20-minute blended sessions in Cohort 2 yielded no significant gain. This pattern suggests a dose-response relationship in which brief exposure may not be enough to translate better engagement into examination improvement. This agrees with previous anatomy education studies showing that adequate time for active VR exploration can enhance learning (Zhao et al., 2020). The absolute gain in mean score of about 3% is modest, but in this high performing-performing group, even a small shift may be educationally meaningful.

The grade distribution analysis highlights the benefit of intensive VR. The more than doubling of 'A' grades in Cohort 3 matches observations of previous studies (Hsieh et al., 2025; Huai et al., 2024), suggesting that VR helps students transition from standard to excellent understanding. The upward trend in 'A and A+' grades across VR-integrated cohorts indicate that VR may provide a higher ceiling for top-performers by offering structural clarity that 2D methods. These results align with our earlier qualitative study (Chiyanika et al., 2025), which reported high engagement but also identified limited access technical constraints. Taken together, these findings suggest that low-intensity VR may improve engagement and perceived understanding without producing a measurable gain in final academic performance, reinforcing the value of VR as a supplement rather than a replacement for traditional methods.

These results suggest that VR is valuable for teaching complex anatomical regions where 3D spatial reasoning, especially neuroanatomy, the pelvis and cross-sectional relationships. The success of Cohort 3 demonstrates that repurposing individual consultation time for structured VR sessions is an effective trade-off that did not require additional curriculum hours. However, wider implementation still requires adequate headset availability, technical support, staff training, and suitable space. The group-based screen-cast format reduced equipment demand and supported peer discussion but limited individual hands-on time. Ultimately, the findings reinforce that for technology to significantly impact grades, it must be implemented as a dedicated, high-dosage intervention with tasks aligned directly with module outcomes.

This study has limitations. Different cohorts over three years introduce potential cohort effects despite comparable entry scores, the same teaching team, stable course outcomes, and an unchanged assessment blueprint. The findings should therefore be interpreted as showing association rather than definitive causation. Results from a single department may also vary elsewhere. In addition, engagement and perceived learning were not collected uniformly across

cohorts, and objective spatial reasoning, long-term retention, and clinical skill transfer were not assessed.

5. Conclusion and Future Directions

VR integration significantly enhances human anatomy performance for radiography students when implemented with sufficient intensity. In this study, only the cohort that received six dedicated one-hour VR sessions achieved significantly higher performance than the traditional cohort, indicating that extended immersion is important for mastering 3D spatial relationships beyond what traditional methods alone can offer. Future work should confirm these findings in randomized or crossover designs within the same cohort and should examine broader outcomes and long-term competencies, including student engagement, objective spatial reasoning, long-term retention, clinical performance and imaging interpretation. Integrating AI for adaptive learning and multi-user VR environments for remote collaboration may further optimize outcomes. Practically, institutions should prioritize protected, curriculum-embedded VR lab time over brief, ad hoc demonstrations, and ensure that VR activities align with learning outcomes, assessment expectations, and implementation infrastructure.

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