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Impact of 3D Virtual Applications on Academic Performance in Musculoskeletal Anatomy among Peruvian Medical Students

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ABSTRACT

The study investigated how utilizing a 3D virtual application relates to academic performance in Peruvian medical students, while also exploring additional factors that could impact their academic outcomes." We carried out a cross-sectional analytical study involving students enrolled in the Musculoskeletal System course in the first semester of 2019. Participants provided information through a structured data form and completed the adapted Self-Directed Learning Readiness Scale (SDLRS) by Fisher, King, and Tangle. To explore the link between effective use of the 3D application and academic performance, linear regression analyses were conducted. Additional factors influencing academic performance were examined using nested models, with β coefficients estimated via manual forward selection. The study included 187 medical students, 61% of whom were female, with a median age of 21 years (range 20–22). The average grade was 13.5 ± 2, and only 21% reported consistently using a 3D application. After adjusting for covariates, there was no significant link between 3D app usage and academic performance (aβ = 0.17; 95% CI: -0.45 to 0.80). Academic performance was negatively associated with age (aβ = -0.22; 95% CI: -0.39 to -0.06) and prior failure in anatomy or physiology courses (aβ = -2.11; 95% CI: -2.9 to -1.8), while engagement in extracurricular activities showed a positive association (aβ = 0.75; 95% CI: 0.25 to 1.24)." Proper utilization of a 3D application for learning musculoskeletal anatomy did not show a significant impact on students' academic performance.

Keywords: Anatomy, Academic performance, Medical (MeSH NLM), Education, Self-directed learning

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Introduction

In recent years, medical education curricula have undergone multiple changes, likely driven by rapid technological advancements and the growing availability of digital tools for students [1]. While traditional textbook-based methods remain widely used for learning anatomy [2], contemporary teaching approaches [3] and the increasing emphasis on self-directed learning [4] have introduced virtual tools that are integral to e-learning strategies [5]. Consequently, universities and educational institutions have incorporated interactive video lectures, online learning materials, and downloadable virtual applications [6], providing students with a more detailed, dynamic, and comprehensive perspective of human anatomy.

Several studies have evaluated the effectiveness of e-learning tools in health professional education. For example, in Norway, second-year medical students who supplemented their immunology course with electronic materials achieved higher exam scores compared to those who did not [7]. Similarly, research in the Netherlands [8] and Canada [9] indicated that traditional textbook-based anatomy study can pose challenges, whereas 3D visualization methods may offer greater learning benefits [8]. Conversely, other studies have reported no significant relationship between 3D application use and academic performance. In South Korea, first-year medical students' use of a 3D anatomy atlas did not significantly affect their anatomy and embryology exam results [10]. Likewise, an

Australian study involving chiropractic students found no association between neuroanatomy scores and the use of 3D applications [11].

In Latin America, research on e-learning in medical education is limited [12–14], and its relationship with academic performance remains largely unexplored. Most existing studies were conducted over five years ago [12, 14], before the latest technological advances. In Peru, e-learning has been applied in some contexts, such as online scientific research courses [15, 16]; however, its impact has not been specifically evaluated, and there is no evidence assessing the relationship between virtual application use and academic outcomes in the country.

The Musculoskeletal System course is an in-person class where instructors teach anatomical structures, including their insertions, innervations, and movements. Mastery of this system is crucial for developing competent medical professionals. Assessments in this course include both group and individual evaluations. Individual tests, primarily multiple-choice, assess students' understanding of musculoskeletal anatomy, physiology, and pathology. Group assessments, conducted orally and in writing, evaluate students' preparation, ability to identify anatomical landmarks, and engagement in clinical case discussions.

Currently, numerous virtual applications provide three-dimensional representations of human anatomy [17]. These 3D tools can help students develop spatial visualization skills, which may be beneficial for future surgical practice [10]. The present study aimed to investigate the association between the use of a 3D application and academic performance among Peruvian medical students enrolled in the Musculoskeletal System course during the first semester of 2019. Additionally, this study examined other factors potentially associated with academic performance.

Materials and Methods

Study design

An analytical cross-sectional study was carried out among medical students at a Peruvian university who were enrolled in the Musculoskeletal System course during the first semester of 2019. The course provided opportunities to use various complementary learning tools, including 3D applications and human anatomy models. Notably, no dissection sessions were conducted during the semester.

Study population

The reference sample size was calculated using Epidat v4.2, based on a 95% confidence level, 80% statistical power, and an equal ratio between groups. The expected standard deviations were 10.13 for students using traditional study methods (books and lectures) and 10.03 for those using 3D applications, with a mean difference of 4.69 [18]. This calculation yielded a minimum required sample size of 148 students; however, we aimed to include all eligible participants. A total of 292 students were enrolled in the course during the first semester of 2019.

Eligibility criteria included medical students enrolled in the Musculoskeletal System course for the first time during the first semester of 2019. Exclusion criteria comprised students who withdrew before the first assessment, those enrolled in fewer than four courses during the semester, and students who were concurrently working while studying.

Variables

Outcome: academic performance

We measured academic performance using the final GPA (0–20) of students in the Musculoskeletal System course for the first semester of 2019.

Exposure: use of 3D app

Use of a 3D application was defined as students' self-reported use of a 3D virtual app more than once to study and prepare for Musculoskeletal System assessments. Considering that the course included two theory-practice sessions per week, students who used the app 4–7 times per week were classified as having adequate use, whereas those who used it less than three times per week or not at all were classified as having inadequate use.

Other variables

The analysis also considered variables such as students' age, gender, living arrangements, involvement in extracurricular activities, total number of courses taken during the first semester of 2019, prior failures in anatomy or physiology courses, weekly study hours for the Musculoskeletal System course, and details regarding the 3D application, including its name, frequency of use, and image quality.

Additionally, we assessed students' satisfaction with the 3D application through three measures: its usefulness, overall perception, and preference. Readiness for self-directed learning was evaluated using the Self-Directed Learning Readiness Scale.

Characteristics of the instrument and validation

A data collection form was developed to include all previously mentioned variables. Additionally, the study employed the Self-Directed Learning Readiness Scale (SDLRS), adapted by Fisher, King, and Tangle in 2001 [19]. This instrument contains 40 items scored on a 5-point Likert scale, ranging from 1 ("strongly disagree") to 5 ("strongly agree") [20], and assesses students' perceptions, motivation, and skills related to autonomous learning. A total score above 150 indicates well-developed self-directed learning abilities [19]. Originally designed for nursing students, the SDLRS has been translated into Spanish and validated for use among Latin American medical students, with a reported Cronbach's alpha of 0.89 [20, 21].

Both the data collection form and the SDLRS underwent qualitative validation using a Delphi methodology. Experts were selected based on academic experience in university teaching (e.g., postgraduate qualifications) and/or at least three Scopus-indexed publications in medical education over the past five years. The instruments were sent via email to five health professionals, who evaluated each item for clarity, coherence, and relevance using a 4-point scale (1 = does not meet criteria, 2 = low, 3 = moderate, 4 = high). Modifications were made according to expert feedback until consensus was reached for both instruments.

To assess comprehension, the finalized instruments were pilot-tested with 30 students enrolled in the Musculoskeletal System course in the first semester of 2020. Items were rated from 0 ("not understood at all") to 10 ("fully understandable"). Finally, Cronbach's alpha was calculated for the SDLRS to confirm its internal consistency and reliability.

Data collection

The finalized survey was uploaded to Google Forms, comprising both the data collection form and the informed consent. Following survey completion, students' GPAs were obtained from the Faculty of Medicine records. Only students who provided consent by agreeing to the informed consent terms were included in the study.

Statistical analysis

Data collected via Google Forms were exported to a Microsoft Excel spreadsheet. A coding process was conducted according to a study-specific variable dictionary, with two independent researchers performing the coding. The resulting databases were then cross-checked to identify coding errors or implausible values. After quality control, the dataset was imported into STATA v15.0 (StataCorp, TX, USA) for statistical analysis.

Numerical variables were described using mean ± standard deviation (SD) or median with interquartile range (IQR), depending on the data distribution, which was assessed with the Shapiro-Wilk test as well as graphical methods (histograms, quantile plots), and measures of skewness, kurtosis, and comparison of mean versus median. Categorical variables were summarized as frequencies and percentages.

Descriptive analyses of sample characteristics were conducted according to academic performance (AP). Since AP was treated as a continuous variable, comparisons were made using the Student's t-test for dichotomous variables and ANOVA for variables with more than two categories. Assumptions of normality and homoscedasticity were evaluated for each test, with homoscedasticity assessed via the Levene test.

To examine the association between 3D application use and academic performance, simple and multiple linear regression models were fitted to estimate crude (cβ) and adjusted (aβ) coefficients, along with 95% confidence intervals (95% CI). Statistical significance was set at $p < 0.05$. The multivariable model was adjusted for confounders identified in the literature, including sex, history of prior failure in anatomy/physiology courses, and self-directed learning score. The Wald test confirmed that the number of enrolled courses did not interact with the model. Model assumptions of linearity, normality, and homoscedasticity were verified using studentized residuals.

As an exploratory analysis, additional factors associated with academic performance were examined using simple and multiple linear regression, with coefficients reported as cβ and aβ. Variables were entered using a manual forward selection approach, starting with a null model and adding independent variables sequentially to achieve the most parsimonious model. While the Akaike information criterion (AIC) initially guided model selection, the final decision was based on the log-likelihood ratio test and changes in R^2. Multicollinearity was assessed after each model using the variance inflation factor (VIF), with all values remaining below 4.

Ethics

The study received approval from the Institutional Review Board of the Faculty of Health Sciences at Universidad Peruana de Ciencias Aplicadas (FCS/CEI 065-05-20). Before participating, students were informed about the study's aims and procedures through an online consent form. Access to the survey was restricted to those who actively confirmed their agreement by selecting 'I have read the consent form, and I agree with it. I would like to start the survey.' Participants who consented were optionally asked to provide their university code to allow retrieval of their final GPA. No academic information was collected from any student without explicit consent.

Results and Discussion

Out of 253 students initially enrolled, 66 were excluded due to eligibility criteria or implausible data, leaving 187 participants for analysis.

Among these students, 61% were female, and the mean GPA was 13.5 ± 2.1. Nearly one-quarter (21%) reported a prior failure in an anatomy or physiology course, and 40 students (21%) were classified as having adequate use of a 3D application. In terms of self-directed learning, 66% of students scored above 150 on the SDLRS. The scale demonstrated excellent reliability, with a Cronbach's alpha of 0.97. Additional sociodemographic and academic characteristics are presented in **Table 1**.

Table 1. Sociodemographic and academic characteristics of the study participants, including self-directed learning readiness scores (n = 187).

Variable	Values
Academic performance (average grade)	13.5 ± 2
Age (years)	21 (20–22) [median (IQR)]
Gender	Male: 73 (39%) Female: 114 (61%)
Cohabitation	Lives alone: 24 (13%) Lives with father and/or mother: 126 (78%) Lives with other family: 15 (8%) Lives with friends: 2 (1%)
Extracurricular activities	No: 115 (57%) Yes: 86 (43%)
Previous failure in an anatomy/physiology course	No: 54 (29%) Yes: 133 (71%)
Number of courses enrolled (total)	5.8 ± 0.6
Hours dedicated to studying the Musculoskeletal System	8 (5–10) [median (IQR)]
Use of a 3D anatomy application	Inadequate use: 147 (79%) Adequate use: 40 (21%)
Electronic device used for the 3D app	Cell phone only: 38 (26%) Tablet/iPad only: 73 (50%) Computer only: 13 (9%) Used two devices: 20 (14%) Used all three devices: 2 (1%)
Name of the 3D anatomy app used	Visible Body: 87 (60%) Essential Anatomy: 5 (3%) Complete Anatomy: 8 (5%) Easy Anatomy: 1 (1%) Anatomy 3D Atlas: 41 (28%) Other: 4 (3%)
Frequency of 3D app usage	Once a week or none: 41 (22%) 2–5 times per week: 106 (57%) 6–7 times per week: 40 (21%)
Preparation for self-directed learning	Score ≤150: 64 (34%) Score >150: 123 (66%)
Self-directed learning scale score	155 (148–165) [median (IQR)]

∗Mean ± standard deviation.
†Median (interquartile range).

In the bivariate analysis, students with a history of failing an anatomy or physiology course had significantly lower GPAs compared to those without prior failures ($p < 0.001$). Conversely, students who participated in extracurricular activities demonstrated higher GPAs than those who did not ($p = 0.003$). No significant differences were observed in academic performance based on adequate use of the 3D application (p = 0.944) or achieving a score above 150 on the Self-Directed Learning Scale (p = 0.073) **(Table 2)**.

Table 2. Academic performance stratified by sociodemographic and academic characteristics of the surveyed students (n = 187).

Variable	Category	Academic Performance (Mean ± SEM)	p-value
Gender	Male	13.6 ± 0.2	0.874
	Female	13.5 ± 0.1	
Extracurricular activities	No	13.1 ± 0.2	**0.003**
	Yes	14.1 ± 0.2	
Previous failure in an anatomy/physiology course	No	15.2 ± 0.3	**<0.001**
	Yes	12.9 ± 0.1	
Use of a 3D anatomy application	Inadequate use	13.6 ± 2.1	0.944
	Adequate use	13.5 ± 1.9	
Frequency of 3D app usage	Once a week or none	13.5 ± 2.3	0.988
	2–5 times a week	13.5 ± 2.0	
	6–7 times a week	13.5 ± 1.9	
Self-directed learning scale score	≤ 150	13.1 ± 0.2	0.073
	> 150	13.7 ± 0.2	

∗Mean ± standard deviation.

In the multivariate model, students who used the 3D application adequately showed a marginal increase of 0.17 points in their GPA compared to those with insufficient or no use; however, this difference did not reach statistical significance (p = 0.580) **(Table 3)**. Exploratory analyses identified several factors associated with academic performance: older age was negatively associated (aβ = -0.22; 95% CI: -0.39 to -0.06), participation in extracurricular activities was positively associated (aβ = 0.75; 95% CI: 0.25 to 1.24), and a history of failing an anatomy or physiology course was linked to lower GPA (aβ = -2.11; 95% CI: -2.9 to -1.8) **(Table 4)**.

Table 3. Relationship between 3D application usage and academic performance in the Musculoskeletal System course, adjusted for confounders.

Variable	Category	Crude Model		Adjusted Model*	
		cβ	95% CI	p-value	aβ
Use of a 3D App	Inadequate use	Ref.		Ref.	
	Adequate use	–0.03	–0.75 to 0.70	0.944	0.17

∗Adjusted for sex, prior failure in an anatomy or physiology course, and Self-Directed Learning Scale score.
†Confidence interval.

Table 4. Determinants of academic performance in the Musculoskeletal System course.

Variables	Bivariate Analysis			Multiple Regression (Parsimonious Model)		
	β	**95% CI**	**p-value**	**Adjusted β**	**95% CI**	**p-value**
Age (years)	-0.40	-0.58 to -0.21	<0.001	-0.22	-0.39 to -0.06	0.008
Gender						
Male	Ref.	-	-	-	-	-
Female	-0.05	-0.66 to 0.56	0.87	-	-	-
Cohabitation						
Lives alone	Ref.	-	-	-	-	-
Lives with parents	0.59	-0.30 to 1.49	0.19	-	-	-
Lives with another family	-0.02	-1.35 to 1.31	0.98	-	-	-
Lives with friends	-0.08	-3.07 to 2.90	0.95	-	-	-
Extracurricular Activities						

No	Ref.	-	-	Ref.	-	-
Yes	0.90	0.30 to 1.48	0.003	0.75	0.25 to 1.24	0.003
Previous Failure of Anatomy/Physiology						
No	Ref.	-	-	Ref.	-	-
Yes	-2.36	-2.91 to -1.80	<0.001	-2.11	-2.67 to -1.56	<0.001
Number of Courses Enrolled	0.08	-0.39 to 0.55	0.72	-	-	-
Hours of Study	0.04	-0.01 to 0.09	0.13	-	-	-
3D App Use						
Inadequate use	Ref.	-	-	-	-	-
Adequate use	-0.03	-0.75 to 0.69	0.94	-	-	-
Self-Directed Learning Score						
≤150	Ref.	-	-	-	-	-
>150	0.57	-0.05 to 1.19	0.073	-	-	-

*Beta coefficient.
†Confidence interval.
††Estimated by *manual forward selection*.

Main findings
Use of a 3D application for learning Musculoskeletal System anatomy was not linked to improved academic performance. Despite the majority of students reporting adequate use and perceiving the application as a helpful study resource, this did not translate into higher final GPAs for the course.

Use of a 3D application and academic performance
Evidence regarding the impact of 3D virtual resources on academic performance is mixed. Our findings align with those reported by Park S *et al*. (2019) and Meyer AJ *et al*. (2016) [10, 11], which also found no significant association. Similarly, a prior review indicated that students generally preferred traditional study methods, such as textbooks and lectures, over digital applications [22].
In contrast, other studies involving medical [23] and psychology [24] students that employed pre- and post-test designs observed performance improvements in students who used virtual applications compared to those relying on textbooks. These results suggest that 3D applications may enhance short-term learning outcomes, though they do not replace other study methods that students favor.
Practical benefits of virtual applications for anatomy study include the ability to examine anatomical structures from multiple angles in three dimensions [8]. Nevertheless, our study, along with previous research, indicates that many students continue to prefer traditional approaches, such as textbooks, over 3D applications for learning anatomy.

Factors associated with academic performance
Our results showed that students with a history of failing an anatomy or physiology course had lower GPAs compared to those who had never failed. This may be due to differences in study habits, with students who have not failed potentially demonstrating better planning, organization, and motivation in their learning compared to those with prior course failures.
Students who participated in extracurricular activities also achieved higher GPAs. Given that the extracurricular offerings at the university are primarily sports-related, this finding could reflect several physiological and cognitive benefits of regular physical activity, such as enhanced cerebral blood flow, neurogenesis, increased neurotrophin and neurotransmitter levels, and improved neuronal plasticity, all of which can support learning and memory [25].
Conversely, we observed that older students tended to have lower final GPAs in the Musculoskeletal System course. Similar findings have been reported in previous studies, showing an inverse relationship between age and academic performance [26, 27]. This may be partly explained by older students having a history of prior course failures, meaning their GPA could reflect accumulated challenges in academic progression throughout the medical curriculum.

Limitations

Several limitations of this study should be acknowledged. First, the cross-sectional design prevents any inference of causality. Second, the external validity of our findings is limited, as the study focused exclusively on students from a single semester enrolled in a specific anatomy course. Third, the use of a self-administered questionnaire introduces the potential for response errors and social desirability bias. Nonetheless, this limitation did not apply to the final GPA data, which were obtained directly from the Faculty of Medicine to ensure accuracy and reliability.

Conclusion

Our study found no association between the use of a 3D application for learning musculoskeletal system anatomy and academic performance. Considering the scarcity of related research in Latin America, further studies are needed to determine whether virtual anatomy applications can meaningfully impact medical students' learning. We suggest that future research should investigate potential long-term effects on academic outcomes, ideally using randomized study designs.

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Conflict of Interest: None

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Ethics Statement: None

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