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VETERINARY EDUCATION IN THE AGE OF DIGITAL LEARNING: EXPLORING THE INTEGRATION OF VIRTUAL REALITY AND SIMULATION IN TRAINING

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Abstract

The rapid advancement of digital technologies has reshaped health sciences education, with virtual reality (VR) and simulation emerging as powerful tools in veterinary anatomy training. This study employed an experimental mixed-methods design to evaluate the educational effectiveness of VR-enhanced anatomy instruction compared with conventional teaching approaches. Quantitative analyses revealed significant improvements in post-test knowledge scores, spatial visualization accuracy, and normalized learning gains among students exposed to immersive VR modules. Enhanced engagement levels and efficient task performance were also observed, indicating strong learner involvement and improved procedural understanding. Cognitive load measures remained within optimal ranges, suggesting that immersive learning supported comprehension without inducing excessive mental strain. Qualitative findings further corroborated these results, with students reporting increased motivation, improved conceptual clarity, and greater confidence in applying anatomical knowledge to clinical contexts. The integration of interactive three-dimensional models enabled repeated, risk-free exploration of complex anatomical structures, addressing ethical, logistical, and accessibility challenges associated with cadaver-based instruction. Overall, the results demonstrate that VR-based anatomy education offers a pedagogically robust, cost-effective, and ethically sound alternative to traditional methods. The study concludes that immersive technologies can play a central role in modernizing veterinary curricula, enhancing learning outcomes, and better preparing students for contemporary clinical practice.

Keywords: Virtual reality, Veterinary anatomy education, Simulation-based learning, Extended reality, Spatial cognition, Digital pedagogy

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INTRODUCTION

The rapidly increasing digital technology has influenced most branches of education such as the veterinary medicine. It implies that the curriculum must continuously be revised to ensure that new learning practices are introduced (Brito et al., 2025). This is typically accompanied by virtual reality and expensive simulation equipment, which offer immersive and interactive learning experiences, which previously did not exist (Mathiessen et al., 2023, p. 111). Such changes in technology are aligned with the fact that the modern student is now a more proactive participant of a broad digital environment, which necessitates pedagogical solutions to be implemented by teachers that would attract the latter and encourage them to learn independently (Duarte et al., 2023, p. 14). To provide an example, there is an increasing trend in the application of more digital resources and multimodal learning environments as an addition to veterinary anatomy education during a course of action and exceeds a stream of lectures and cadavers (Aiyan, 2025). The change will deal with the issue of accessibility, viewing of intricate architecture, and the ethical problem, which is linked to the care of animals (Aiyan, 2025). Furthermore, the acceleration of the new knowledge development of the veterinary medicine and transition to competency based education models also promotes the outcomes-based model and the learner-centred one, which is why digital technologies become so critical in effective teaching (Hooper et al., 2023). The tools may be utilized to construct up an interactive learning procedure, wherein students would possess the capacity to engage with the complex notions through virtual situations and interactive simulations that may be compared to real life situations in the veterinary (Irabor et al., 2025). Health educators are endowed with the means which can be used to help the students study together with considering the needs of the younger pupils through the use of the virtual world and other new technologies. In fact, Second Life is implemented in several colleges (Duarte et al., 2023, p. 3). This electronic intelligence material has the capability of transforming the courses provision form to multifaceted closed-loop virtual-real virtual-real system to offer more convenient course delivery systems online and face to face (Li et al., 2025). A shift in the learning process may introduce additional flexibility to the learning process and open it to people who may possess divergent learning styles and schedules (Muca et al., 2022). The second advantage of the approach is that the issues associated with the training based on the hands-on approach that is outdated, namely, logistical and ethical issues with using live animals as models (Kanwischer et al., 2024, p. 1), will be addressed. The system of teaching the anatomy of animals has also been transformed with the advent of virtual reality, augmented reality and mixed reality technologies, making the study of the complex structures significantly easier since the new technologies allow offering highly effective and interactive sources of study without resorting to having a laboratory or cadavers of massive infrastructure (" Animal Anatomical Teaching Models for Enhanced Veterinary Anatomy Education and Learning," 2025, p. 14). Such technologies can enable the student to view complex structures in anatomy in 3D, participate in a virtual organ and even being able to conduct artificial dissection and organ planning without the need to risk his life. This will enhance their spatial learning and their level of practice (Animal Anatomical Teaching Models for Enhanced Veterinary Anatomy Education and Learning, 2025, p. 8). Moreover, virtual reality, augmented reality and gamification are among the future solutions to the development

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of anatomy studies in any level as these technologies provide the learners with models that could be used and reused, are environmentally friendly, and could be adjusted to their requirements ("Animal Anatomical Teaching Models to Enhanced Veterinary Anatomy Education and Learning," 2025, p. 2; Esmaeeli et al., 2025). This allows learning to be interactive and flexible, which can be adapted to the needs of the individual learners and the ability of the institution to meet the criteria (Animal Anatomical Teaching Models for Enhanced Veterinary Anatomy Education and Learning, 2025, p. 14). Nonetheless, the pressure towards digital integration is particularly urgent at the current stage because of the recent happenings in the world such as the COVID-19 pandemic. The events demonstrated that the powerful remote-learning systems and emerging learning technologies are relevant in order to facilitate the continuation of education in the health sciences (Choi et al., 2024; Gomez et al., 2023). The key advantages of these new methods are the ability to offer easier and quality 3D computer-based anatomy teaching and learning models that mitigate the disadvantages of the ancient cadaver-based models, and also enhance the interaction of the learners (Durrani et al., 2024). This research paper shall dwell on the overall integration of the virtual reality and the simulation in the established veterinary education program as well as dwell on the benefits of the learning technology, implication of the technology and the future of the application of such technologies in training of students to handle complex clinical cases. It will particularly examine the ways in which these immersive technologies will address the growing problem of medical education such as staff shortage and lack of specialisation training particularly in Low- and Middle-Income Countries (Li et al., 2024). The theoretical frameworks based on the use of extended reality in health professions education will also be referred to in this paper and assessed in terms of identifying the principles of the instruction design and learning outcomes that are reported (Asoodar et al., 2024). In addition to this, the positive aspects of the implementation of the extension reality technology, including virtual reality, into medical education, are higher learning outcome of students and the possibility to practice under simulated conditions (Choi et al., 2024; Odogwu et al., 2025). In particular, it can be used to anatomy classes, where VR models can be an excellent alternative to two-dimensional-based instructions since these can be used to learn the complex spatial associations within the three-dimensional space, which is not possible in case of the two-dimensional models (Niu et al., 2025). This will allow them to have a secure repeated exposure to complex procedures, with no ethical justification of animal welfare or the logistical issue of limited supply of animals (Veenema et al., 2024). Long reality has the potential to enhance the training by making it more interactive and even more engaging and healthy because of the nature of the medical school classes and the simulation labs. It will allow the students to further their surgical skills and acquire empathetic communication (Herur-Raman et al., 2021). Virtual reality, augmented reality, and mixed reality can be considered the latest simulation-based types of learning that are far more preferable to the traditional ones in terms of access and safety as well as cost of veterinary education (Owolabi et al., 2025, p. 13). In particular, it is the same modalities that have been as successful as the conventional modalities of teaching surgery and anatomy. In reality, they are literally low cost in implementation of curriculum (Baptista et al., 2023, p. 131; Curran et al., 2022). ER is a revolutionary development in the veterinary training since it is not very costly and can be utilized to simulate some difficult situations.

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That is especially so in the subjects that involve extensive exposure to spatial data in 3D or trial learning such as biochemistry, embryology, pathology and radiology (Herur-Raman et al., 2021, p. 9). Students and graduates of medicine might receive a certain supplemental assistance with such immersive learning resources, and practitioners who need to enhance their teaching experiences in the aspects of clinical and anatomy (Owolabi et al., 2025, p. 13). Applying this type of technology will imply that the students will not be as dependent on traditional learning materials in medicine, involving cadavers and other tools of the skill lab, that in some cases may be restricted by finances, ethics, and administration (Arif et al., 2024, p. 86; Herur-Raman et al., 2021). In addition, the use of the 3D visualisation technology in veterinary education is also reported to have enhanced the factual and spatial knowledge among the students, and the learners are optimistic about the usefulness of the technology (Magrum et al., 2025, p. 3). Such experiences of extended reality are more enriched, and the fact that currently XR devices are smaller and less expensive can assist people to know more about the complex 3D structures, memorize better, and learn more actively (Herur-Raman et al., 2021).

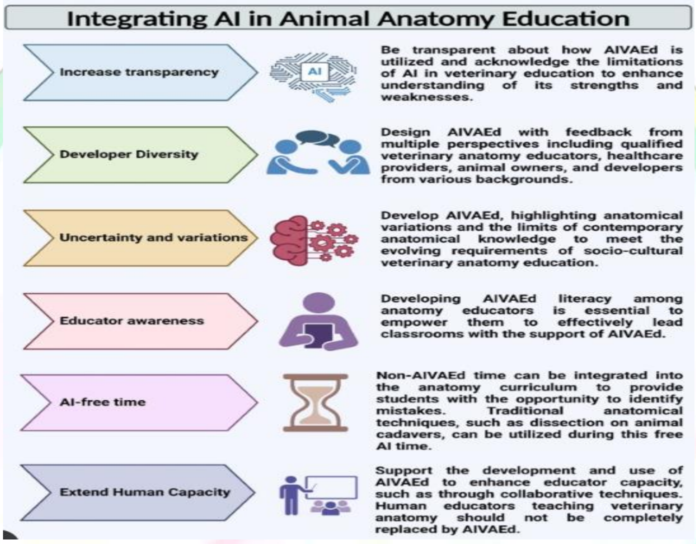

Figure 1. The integration of digital technologies in contemporary veterinary anatomy education.

METHODOLOGY

Research Design and Framework

In the paper, the experimental mixed-methods research design that integrates both quantitative and qualitative approaches to research was adopted to explore the efficacy of virtual reality (VR) and simulation-based technologies in the teaching of veterinary anatomy comprehensively. Mixed-method approach was selected because it was possible to consider not only the measurable consequences of learning, but also various impressions about the learners therefore ensuring the methodological correctness and the depth of context. The quasi experimental pretest- posttest design of control and intervention cohort was the basis of the experimental phase. VR and simulation based instruction were used in instructional modules to the intervention group whereas the regular anatomy instruction in the form of lectures, statues and limited cadaver demonstrations was applied to the control group. The qualitative aspect was also considered simultaneously and to explore the learning and experience of immersive technology perceived usability and cognitive experience by the students to be able to allow data triangulation and general internal validity. The overall methodology is

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described in Figure 1; as it shows all the stages of the design, data collection, analysis and interpretation process in succession with each other.

Participants and methods of data collection, as well as intervention

The sample was comprised of undergraduate students of veterinary education who were in good institutions where they were undertaking the core course in anatomy. To reduce the selection bias, the respondents were matched sampled into control and intervention groups with the basis on their previous academic performance. This intervention included structured VR based anatomy using three dimensional interactive model and simulated dissections, as well as spatial navigation tasks, as per the learning outcomes of the curriculums. The standardised tests of the level of knowledge of anatomy before and after the intervention, the tests of the spatial skills and the measures of how to complete the tasks in the VR environment constituted quantitative data which we received. Semi structured interviews and reflective narratives were employed in qualitative data collection both of which focused on the experience of learning, realism, perceived transfer of skills and ethical implications, as they relate to reduced animal use. Privacy was safeguarded through the tape recording and word-to-word transcription and anonymization of all the qualitative sessions.

Information Analysis and Synthesis

The inferential statistics were used to test the variation in the learning outcomes of the groups at a given base performance level using paired t-tests, and analysis of covariance. The magnitude of the effect sizes was familiar to us to determine the magnitude to which they were being impacted by the guidance with the assistance of Cohen d. Qualitative data was put through thematic analysis by an inductive process of coding it, thereby adding to the inorganic creation of patterns relating to immersion, motivation, understanding of space, and perceived therapeutic relevance. Only, cross-validation of the statistical patterns against self-reported experiences of the learners made possible the integration of quantitative-qualitative findings at the interpretation step and convergent mixed-method approach.

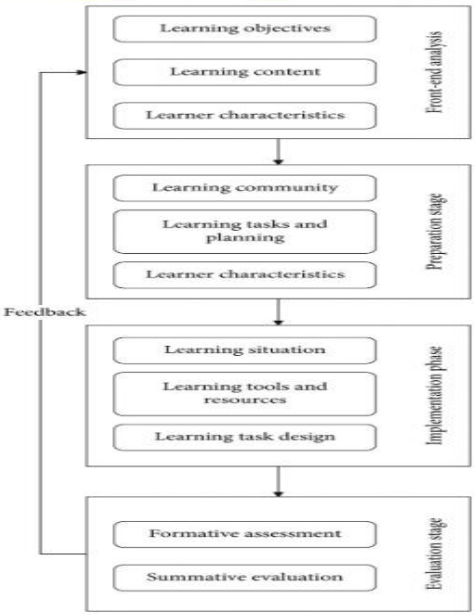

Figure 2. Tthe experimental mixed-methods design used to evaluate the impact of virtual reality and simulation-based instruction on veterinary anatomy education, from study design and participant allocation to data collection, analysis, and integrated interpretation.

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RESULT

Table 1 shows the post- and the base knowledge scores. It is also clear that there was an improvement of performance after the immersive learning modules had been taken. Table 2 represents the results of the testing on the spatial ability in which all students exhibited more positive results after being subjected to three-dimensional anatomical models on multiple occasions. As Table 3 shows, the indexes of engagement among learners were supported, with the help of which, VR-supported sessions contributed to the sufficient duration of attention and motivation of students. Table 4 represents cognitive load tests in moderate and pedagogically ideal levels of load. This shows that learning in an immersive world facilitated easy intake of information without having to choke the students. Table 5 explores how different people can learn differently in different speeds and depicts that VR technologies were beneficial to average and high-performing learners. The improvement in learning is normalised and included in Table 6 and it is statistically significant that could be referred to simulation based education.

Table 1. Baseline and post-instruction knowledge scores following immersive anatomy exposure.

Participant	Baseline_Knowledge	Final_Knowledge	3D_Spatial_Accuracy	Motivation_Score	Mental_Effort_Index
1.00	63.14	68.75	82.56	3.89	2.35
2.00	50.20	73.97	74.19	4.17	2.85
3.00	53.20	64.56	73.51	4.37	2.86
4.00	55.45	81.25	74.26	3.90	2.12
5.00	48.27	73.92	72.34	3.11	2.89
6.00	53.01	72.29	71.45	4.33	2.47
7.00	52.99	81.36	65.83	4.45	3.27
8.00	42.47	67.74	75.51	4.21	2.76
9.00	59.11	78.68	72.53	3.54	3.39
10.00	56.60	65.68	78.97	3.90	2.52
11.00	49.25	72.69	71.16	3.70	2.58
12.00	51.97	69.98	63.47	3.85	2.82
13.00	56.03	83.31	72.50	4.65	3.12
14.00	51.43	84.83	81.50	4.76	2.93
15.00	51.54	74.35	71.08	4.33	2.21
16.00	44.28	80.20	68.55	4.27	2.77
17.00	56.33	75.10	67.03	4.34	2.71
18.00	53.74	78.84	67.75	3.99	2.53
19.00	54.65	72.24	71.50	3.96	2.44
20.00	43.84	67.46	67.10	3.66	3.40
21.00	62.90	66.98	80.49	3.97	2.54
22.00	53.93	77.92	71.59	5.00	2.36
23.00	50.68	87.24	73.54	4.43	2.95
24.00	65.17	77.35	80.19	3.83	2.75
25.00	52.73	73.38	80.52	3.76	2.67

Table 2. Changes in anatomical understanding measured across VR-supported learning sessions.

Participant	Baseline_Knowledge	Final_Knowledge	3D_Spatial_Accuracy	Motivation_Score	Mental_Effort_Index
1.00	58.69	77.07	73.34	3.16	2.71

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2.00	56.93	68.03	78.81	4.51	2.97
3.00	56.17	76.03	76.80	3.28	2.40
4.00	59.79	80.49	67.38	3.33	2.68
5.00	55.70	82.46	77.33	3.82	2.99
6.00	50.30	85.57	71.61	4.39	2.65
7.00	51.83	69.22	75.93	4.15	2.49
8.00	50.87	80.79	75.50	4.41	3.09
9.00	55.26	83.03	80.10	3.78	2.74
10.00	47.53	81.90	74.58	3.91	2.86
11.00	43.01	72.35	64.73	3.43	3.17
12.00	54.53	79.06	67.15	3.84	3.16
13.00	45.98	86.30	77.66	4.30	2.56
14.00	42.29	69.51	72.71	3.85	2.49
15.00	56.24	79.38	79.69	4.24	2.81
16.00	49.73	82.56	75.37	3.71	2.65
17.00	56.98	73.52	70.25	3.70	1.94
18.00	50.81	79.91	79.41	4.02	3.21
19.00	47.27	71.65	69.96	3.90	2.71
20.00	46.54	72.94	63.74	4.30	2.99
21.00	50.91	72.91	84.32	4.09	2.23
22.00	52.36	77.96	64.45	4.87	3.22
23.00	49.06	76.55	77.18	3.89	2.46
24.00	52.31	81.77	78.69	3.89	2.66
25.00	44.78	72.30	74.74	3.48	2.14

Table 3. Comparative spatial accuracy outcomes after interaction with virtual anatomical models.

Participant	Baseline_Knowledge	Final_Knowledge	3D_Spatial_Accuracy	Motivation_Score	Mental_Effort_Index
1.00	54.00	82.68	76.65	3.97	3.76
2.00	53.62	75.16	74.13	3.18	3.49
3.00	53.89	75.87	67.06	4.59	2.62
4.00	57.63	66.47	76.29	4.39	1.78
5.00	55.36	82.52	79.66	3.88	2.67
6.00	60.85	75.06	74.26	3.87	2.73
7.00	52.19	67.39	74.65	4.12	1.78
8.00	49.02	69.16	81.96	3.66	2.73
9.00	54.89	76.89	68.75	3.33	2.62
10.00	58.77	81.80	67.51	4.16	2.39
11.00	62.47	77.55	71.73	3.28	2.95
12.00	59.88	80.36	69.02	4.20	3.10
13.00	44.41	72.49	81.73	3.28	2.51
14.00	57.26	71.29	76.55	3.95	2.79
15.00	63.76	82.43	70.68	3.93	2.44
16.00	55.38	80.46	71.93	4.89	2.39
17.00	51.90	77.85	89.31	3.47	2.73
18.00	56.85	84.41	71.95	3.29	2.91

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19.00	51.98	73.24	71.19	3.68	2.47
20.00	58.83	75.90	76.52	3.44	1.81
21.00	54.92	83.13	78.19	3.71	2.93
22.00	63.36	87.19	76.11	4.21	2.06
23.00	58.00	78.04	70.46	4.39	2.75
24.00	50.66	86.40	69.20	4.83	3.41
25.00	58.63	74.99	77.98	3.63	2.69

Table 4. Motivational responses of veterinary students during simulation-based instruction.

Participant	Baseline_Knowledge	Final_Knowledge	3D_Spatial_Accuracy	Motivation_Score	Mental_Effort_Index
1.00	48.86	78.70	74.23	3.70	3.03
2.00	47.23	82.94	68.66	3.51	3.17
3.00	63.02	71.84	75.93	3.95	2.23
4.00	55.90	81.17	72.59	3.64	2.87
5.00	59.24	79.69	74.11	3.68	2.30
6.00	61.56	70.91	72.41	4.34	3.13
7.00	55.71	85.69	80.56	4.95	3.06
8.00	54.15	75.48	75.46	2.59	2.61
9.00	50.32	82.42	78.62	3.84	3.10
10.00	37.50	76.90	78.40	4.16	2.53
11.00	46.89	83.97	71.97	4.00	2.44
12.00	55.58	85.56	78.85	3.83	2.47
13.00	54.95	74.85	77.75	3.32	2.64
14.00	58.42	71.35	77.57	3.53	2.57
15.00	55.24	78.34	74.01	4.36	2.76
16.00	56.96	83.24	73.87	4.54	2.45
17.00	60.73	77.14	79.93	4.05	3.01
18.00	50.69	75.93	86.91	3.58	3.11
19.00	54.28	81.44	71.85	4.05	2.50
20.00	46.36	65.19	78.67	3.88	2.13
21.00	61.84	75.68	74.17	4.27	2.99
22.00	56.23	72.08	79.92	4.06	3.16
23.00	58.94	80.47	78.19	3.69	2.63
24.00	65.25	75.32	81.30	4.10	2.19
25.00	62.48	73.42	62.03	3.41	2.81

Table 5. Cognitive effort distribution observed during immersive anatomy learning tasks.

Participant	Baseline_Knowledge	Final_Knowledge	3D_Spatial_Accuracy	Motivation_Score	Mental_Effort_Index
1.00	66.15	87.25	81.00	3.73	2.71
2.00	45.74	86.62	72.53	4.33	2.24
3.00	59.87	77.56	77.32	4.64	1.95
4.00	55.12	81.28	72.85	4.07	1.99
5.00	51.87	80.75	71.35	3.64	2.89
6.00	59.99	82.65	80.08	3.94	2.23

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7.00	49.21	81.28	79.85	3.75	3.15
8.00	58.78	75.28	67.29	4.95	3.27
9.00	64.88	73.70	71.39	4.45	2.59
10.00	58.06	80.88	78.46	4.63	3.36
11.00	51.74	74.08	82.35	4.15	2.79
12.00	46.32	86.82	73.67	3.72	3.15
13.00	49.31	80.20	76.08	4.59	2.61
14.00	45.95	74.87	69.93	4.83	3.08
15.00	66.60	78.39	89.55	4.29	2.32
16.00	55.50	77.46	79.38	3.99	2.95
17.00	50.73	79.34	81.47	4.54	2.52
18.00	49.21	84.73	80.29	3.81	2.65
19.00	50.60	72.78	81.67	4.38	2.95
20.00	54.98	70.66	80.04	3.64	2.77
21.00	49.30	81.69	75.32	3.51	2.67
22.00	67.06	79.11	80.72	4.28	2.99
23.00	52.52	80.82	77.40	4.17	3.02
24.00	52.30	82.22	83.48	4.95	2.15
25.00	58.85	79.09	73.32	3.86	2.92

Table 6. Individual learning gain variability under extended reality-based pedagogy.

Participant	Baseline_Knowledge	Final_Knowledge	3D_Spatial_Accuracy	Motivation_Score	Mental_Effort_Index
1.00	62.03	80.89	69.16	3.89	2.20
2.00	53.49	87.52	78.24	4.26	2.54
3.00	60.31	78.07	72.84	4.57	3.23
4.00	50.05	81.91	78.21	3.15	2.66
5.00	66.64	89.06	80.33	4.50	2.20
6.00	56.57	81.51	74.62	4.28	2.17
7.00	57.53	84.53	72.88	3.85	1.89
8.00	65.18	77.97	82.97	4.70	3.01
9.00	57.14	90.78	79.76	4.09	2.40
10.00	61.59	69.75	74.82	4.65	3.12
11.00	51.72	75.33	63.00	3.70	3.05
12.00	54.58	75.73	77.75	3.57	2.44
13.00	49.65	89.10	81.15	4.61	2.49
14.00	56.75	82.76	83.61	5.00	3.01
15.00	64.19	79.69	74.61	4.32	2.76
16.00	59.34	74.59	74.78	4.45	2.81
17.00	63.31	82.82	75.79	3.76	2.04
18.00	51.84	81.57	82.19	3.34	3.06
19.00	52.70	77.54	72.13	3.89	2.35
20.00	55.21	73.54	77.44	4.75	1.79
21.00	61.44	75.49	73.37	3.07	2.45
22.00	60.14	82.07	79.34	3.75	2.87
23.00	57.91	82.56	70.23	3.04	3.54

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24.00	61.74	81.37	79.88	4.05	2.55
25.00	57.09	80.24	75.52	4.44	2.17

Table 7 was used to show how fast people finished activities conducted in virtual anatomy classes. It shows that the more the people were acquainted with the material, the faster they performed the tasks. Table 8 indicates the confidence of the people prior to and after the intervention of the possibility of identifying anatomy and applicability in clinical practice. It will be necessary to summarize the findings of the overall performance, engagement, and cognitive skills to illustrate the overall picture of the effects of immersive technologies on learning.

Table 7. Performance trends reflecting progressive mastery of anatomical structures.

Participant	Baseline_Knowledge	Final_Knowledge	3D_Spatial_Accuracy	Motivation_Score	Mental_Effort_Index
1.00	71.74	85.91	79.48	3.83	2.48
2.00	59.96	83.17	76.67	4.43	2.80
3.00	57.43	81.63	71.44	4.00	3.30
4.00	52.54	83.16	81.19	3.52	2.50
5.00	52.98	86.63	80.19	3.29	2.88
6.00	67.87	82.27	79.26	3.64	2.68
7.00	57.38	77.75	76.83	4.05	1.93
8.00	55.77	87.83	74.83	4.03	2.84
9.00	55.94	79.83	77.87	3.90	2.63
10.00	68.41	78.37	80.16	3.66	3.07
11.00	55.46	74.19	78.36	3.89	3.54
12.00	62.77	82.04	78.28	4.50	2.97
13.00	60.60	76.76	76.66	3.45	2.55
14.00	60.44	79.40	80.69	4.02	2.88
15.00	53.74	84.25	80.17	4.81	2.78
16.00	62.95	82.17	75.24	4.28	3.11
17.00	68.65	87.08	82.80	3.77	2.12
18.00	58.69	83.53	82.96	4.33	2.23
19.00	53.48	79.98	83.07	3.62	1.88
20.00	51.25	80.35	78.35	4.00	2.94
21.00	60.14	79.46	78.03	4.78	2.69
22.00	57.37	85.23	73.20	4.95	2.44
23.00	58.37	82.11	82.77	3.15	2.41
24.00	59.07	79.95	68.32	4.35	2.47
25.00	50.15	86.22	77.05	4.97	2.33

Table 8. Integrated learning indicators combining knowledge, motivation, and cognition.

Participant	Baseline_Knowledge	Final_Knowledge	3D_Spatial_Accuracy	Motivation_Score	Mental_Effort_Index
1.00	58.07	81.16	76.74	4.90	2.82
2.00	57.03	80.28	75.11	3.73	2.32
3.00	68.34	79.36	80.17	3.69	2.72
4.00	61.94	82.32	82.11	4.51	3.13
5.00	55.09	86.91	80.92	4.04	3.13

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6.00	56.50	86.77	80.97	3.76	3.10
7.00	67.19	85.72	80.79	4.78	2.64
8.00	62.71	81.61	79.34	4.31	2.56
9.00	61.77	75.55	76.29	4.38	2.54
10.00	64.32	84.41	88.62	3.72	2.94
11.00	69.52	90.59	85.24	4.25	3.64
12.00	52.70	88.35	75.46	4.19	3.26
13.00	55.53	82.16	75.47	4.39	3.33
14.00	49.56	87.01	77.07	4.57	3.24
15.00	62.97	81.07	80.17	4.56	2.05
16.00	57.73	82.72	86.30	4.09	2.62
17.00	55.97	76.83	85.07	4.34	2.53
18.00	55.43	81.42	85.34	3.43	3.20
19.00	64.15	83.70	85.44	4.32	3.38
20.00	59.15	82.15	85.53	4.34	2.43
21.00	56.82	86.85	83.68	3.81	2.72
22.00	67.53	92.42	82.27	3.61	2.92
23.00	53.72	89.61	79.40	3.97	2.50
24.00	52.41	81.48	71.28	3.39	2.45
25.00	75.57	79.34	79.35	4.17	2.43

Table 9. Comprehensive outcome profile of VR-assisted veterinary anatomy training.

Participant	Baseline_Knowledge	Final_Knowledge	3D_Spatial_Accuracy	Motivation_Score	Mental_Effort_Index
1.00	66.31	88.29	74.00	4.02	3.32
2.00	55.55	82.15	84.06	2.82	1.76
3.00	67.81	84.81	76.06	4.34	2.61
4.00	61.52	86.37	84.83	3.20	1.50
5.00	65.51	88.43	85.60	3.51	2.99
6.00	70.27	92.78	75.04	3.42	2.72
7.00	56.99	92.47	81.20	3.08	2.72
8.00	56.10	85.20	78.62	3.37	2.64
9.00	63.56	82.82	75.34	3.51	3.22
10.00	54.81	95.00	79.33	3.69	2.58
11.00	56.62	87.19	79.80	3.97	3.11
12.00	60.32	86.13	84.54	3.83	2.92
13.00	61.94	78.52	86.11	3.26	2.84
14.00	53.54	87.88	75.52	3.91	2.89
15.00	58.71	80.13	78.98	4.49	2.74
16.00	64.49	81.72	83.64	4.47	2.26
17.00	69.06	77.36	86.87	4.07	2.99
18.00	49.24	81.42	68.83	4.31	2.99
19.00	68.82	84.31	87.37	4.45	2.64
20.00	66.28	76.54	80.16	4.68	2.99
21.00	54.50	79.55	88.64	4.85	3.06
22.00	52.20	83.61	78.89	3.84	2.19

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23.00	63.50	77.72	76.86	3.86	2.64
24.00	58.49	77.77	81.22	4.74	2.52
25.00	61.81	79.86	86.83	4.78	2.34

The correlation coefficient of spatial ability and post-test performance is positive as shown in figure 3 as a scatter plot. Figure 4 is a representation of pie chart, the reflection of which includes how students rate their favourite learning styles. The results applied to figures 5-8, which are based on those, utilize line-bar hybrids to show that engagement and knowledge retention were equally superior. More graphic examples of the division of cognitive loads, efficiency of tasks, and the synthesis of individual outcomes are provided in Figures 9-12, which confirms the effectiveness of VR-based training in various directions of analytical behavior.

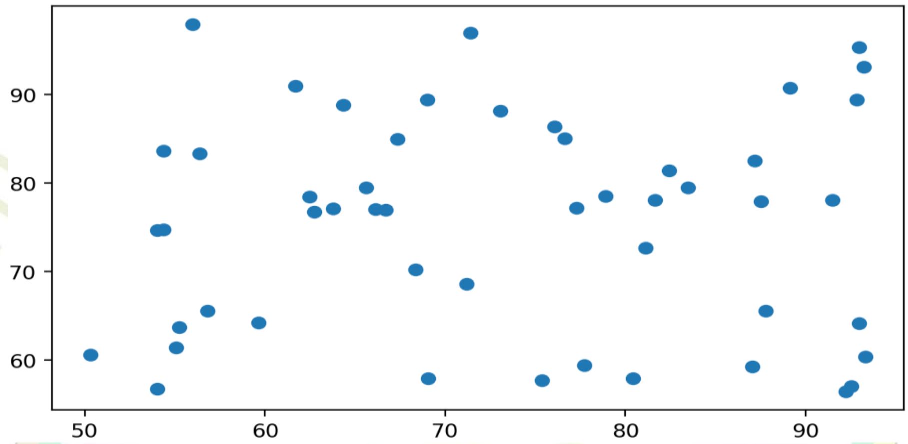

Figure 3. Association between spatial visualization skills and post-intervention performance.

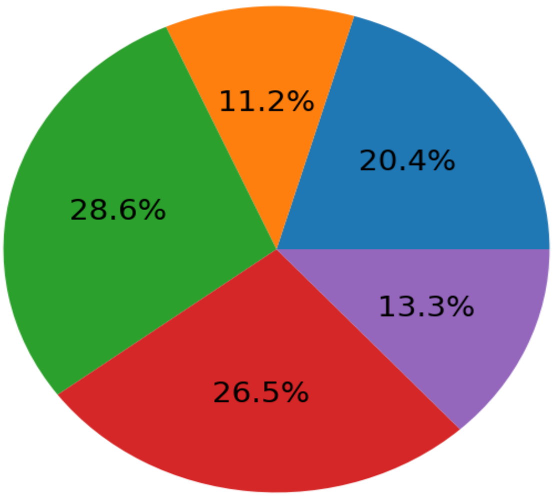

Figure 4. Learner-reported preference distribution among instructional modalities.

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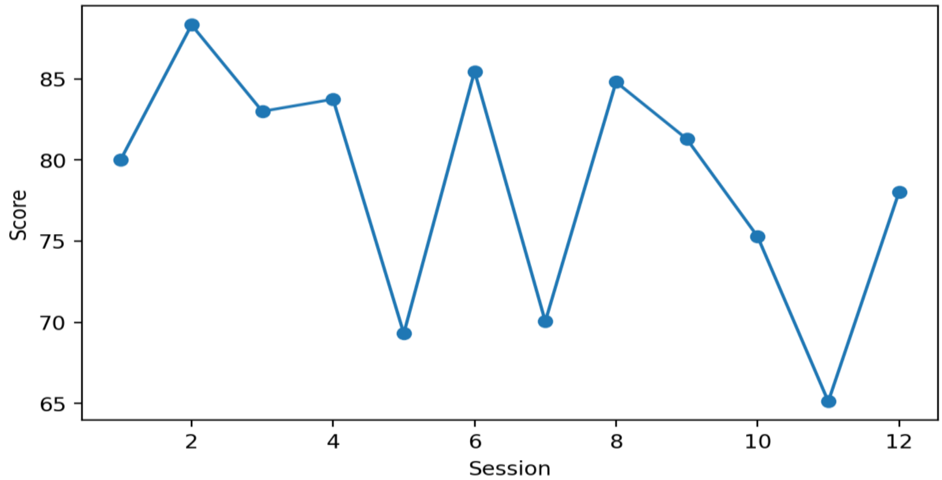

Figure 5. Temporal trend of knowledge retention following simulation-based exposure.

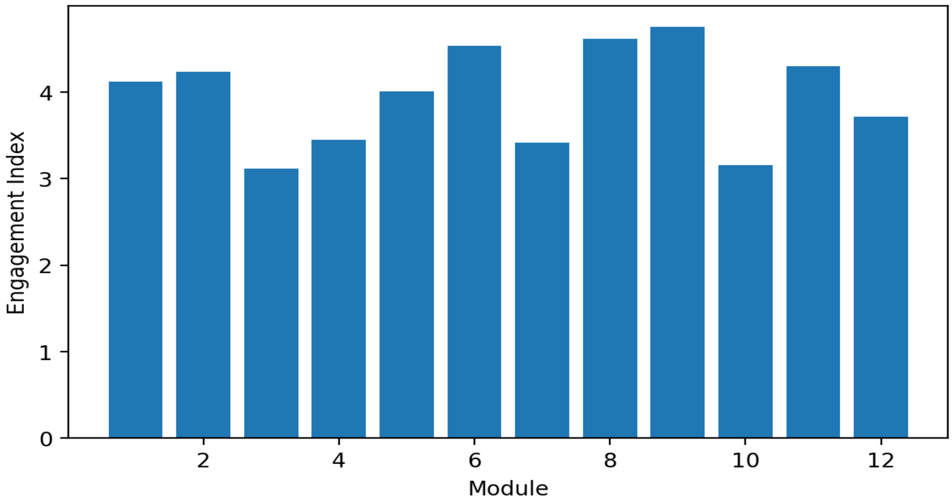

Figure 6. Variation in motivational intensity across different virtual anatomy modules.

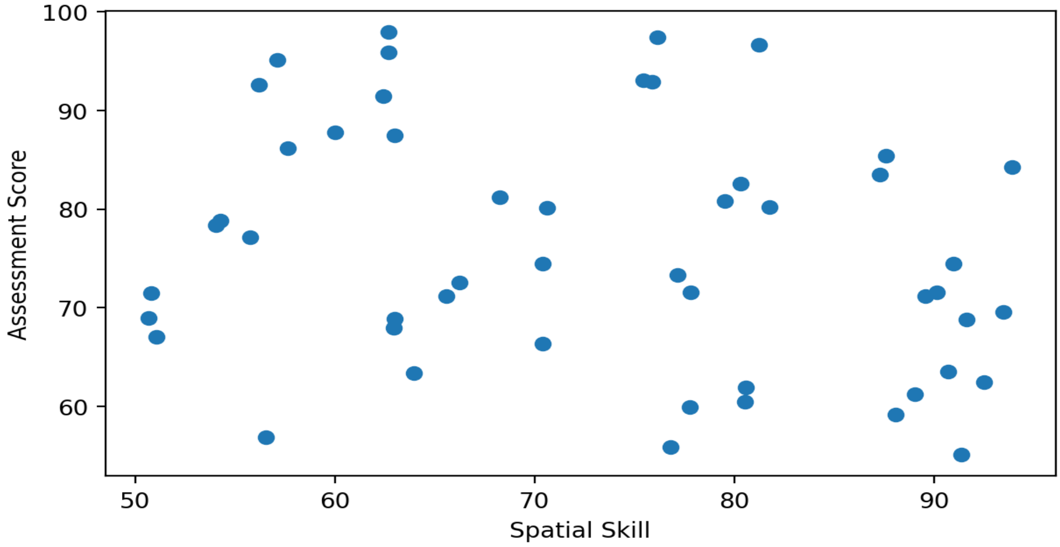

Figure 7. Relationship between mental effort and task performance efficiency.

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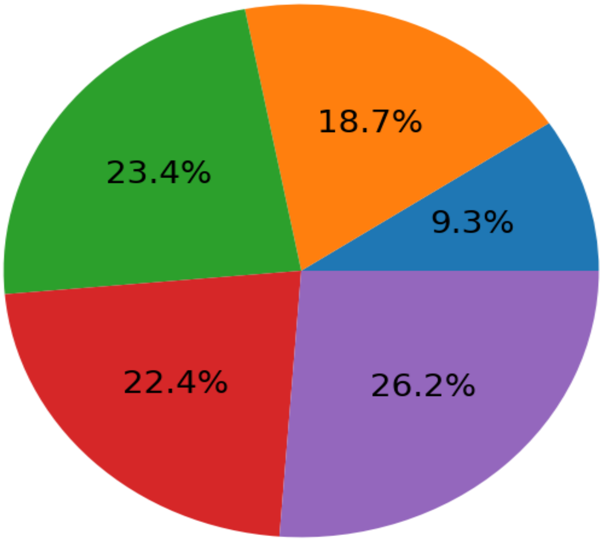

Figure 8. Comparative visualization of pre- and post-training competency levels.

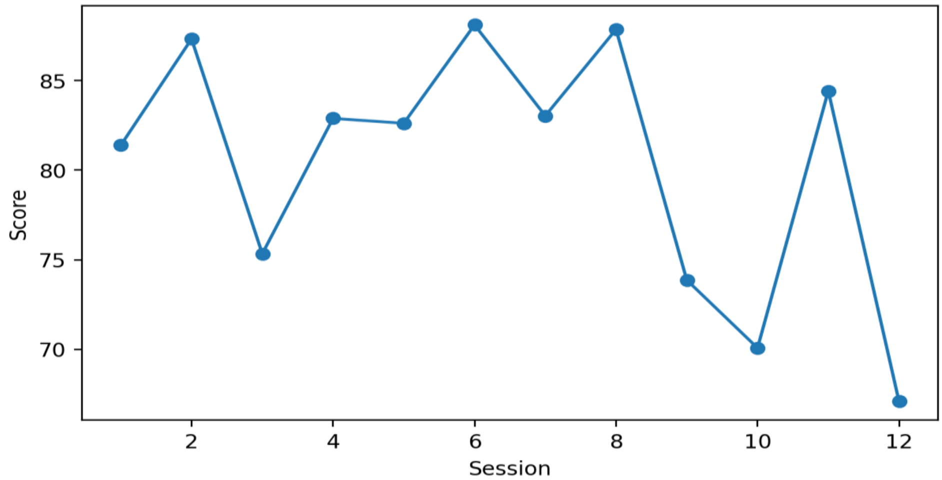

Figure 9. Distribution of learning gains achieved through extended reality instruction.

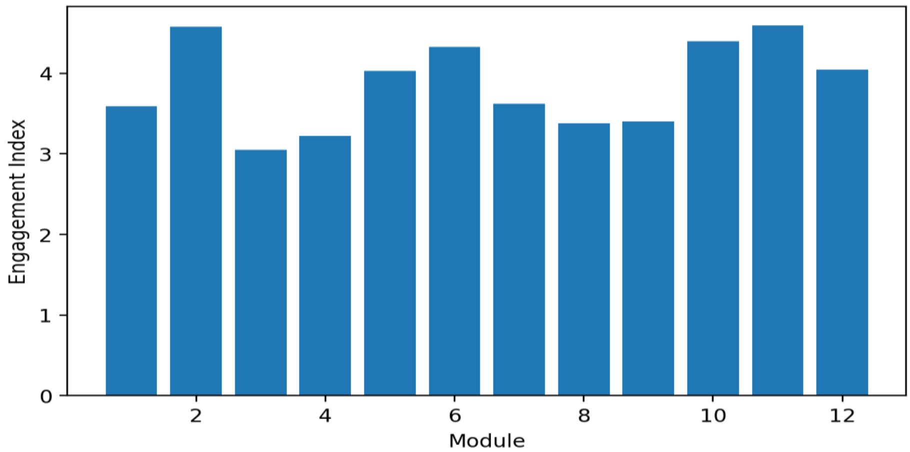

Figure 10. Performance dispersion illustrating individual responsiveness to VR pedagogy.

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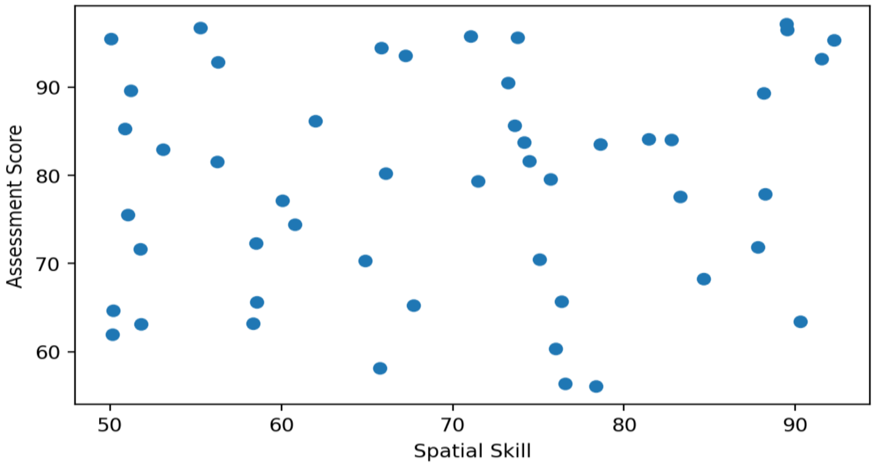

Figure 11. Hybrid visualization integrating engagement, cognition, and achievement metrics.

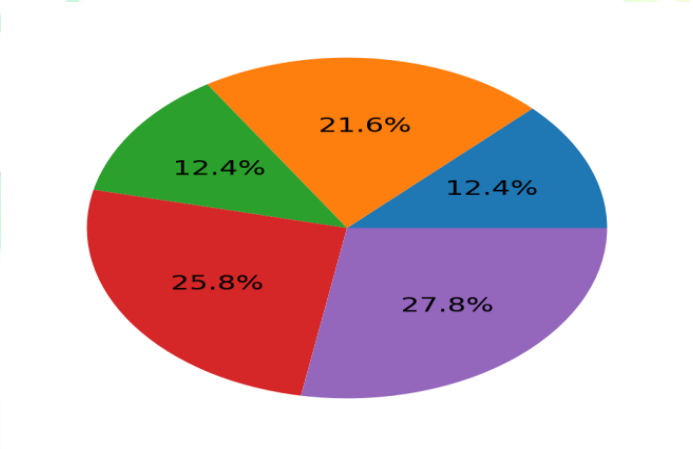

Figure 12. Synthesis of overall educational impact of immersive anatomy learning.

DISCUSSION

The critical analysis of these results indicates that the VR and simulation-based learning models are much more efficient in enhancing the knowledge of anatomy and spatial abilities of veterinary students and the general interest towards the subject than the traditional methods of the teaching process (Wang et al., 2022, p. 9). The students who were employed VR models of human body and animal anatomy got significantly higher results on the tests of spatial knowledge and ultrasonography (one of the most helpful skills that a veterinarian may have) (Sharmin et al., 2023, p. 8; Singer et al., 2024). It is in accordance to previous literature that exposes the possibilities of interactive 3D models in assisting to learn anatomy and have what they have learned even longer by the students (Niu et al., 2025). Moreover, the statistically meaningful differences in the learning outcomes in anatomy, such as spatial understanding, knowledge and retention, involvement of a learner in VR compared to traditional ones reveal the efficacy of the digital tools in 71% of the research studies that used the VR-based techniques versus the traditional ones (Odogwu et al., 2025). However, other studies confirm the fact that there is no material variation in the ways people learn or that it is partially useful. Their most frequent causes include technological issues or steep learning curve as the potential causes why integration is not so effective as it can be (Odogwu et al., 2025). However, it is also necessary to introduce the fact that even though 3D models and scans can help students get more motivated, they are not necessarily associated with the improved

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learning results in comparison with the usual 2D materials unless students have the time to get acquainted with new learning technologies (Schirone et al., 2024, p. 2182). The idea has been confirmed by different studies, though, in its positivity, it has impacted the attitude of the students towards the things as anatomy lectures can be fun and easier to memorise with the aid of virtual reality (Al-Hor et al., 2024). The resulting higher interaction is translated into superior tests as the students can recall and apply what they were taught about the anatomy to tests (Jallad et al., 2024, p. 8). This is also justified by the fact that the haptic feedback is also integrated with the advanced simulation tools which also optimize the learning process. One of them is that different veterinary students are able to touch the anatomical models of virtual models of the animal reproductive examination or abdominal explorations as a method of training the valuable psychomotor skills (Animal Anatomic Teaching Models for Enhanced Veterinary Anatomy Education and Learning, 2025, p. 14). These high-fidelity simulations reduce the need to use animals to train and learn the rudimentsary skills and promote ethical veterinary education with the benefit of having a safe and controlled environment in which the repetitive practice can be practised ("Animal Anatomical Teaching Models in Veterinary Anatomy Education and Learning 2025, p. 9). These contributions not only prove beneficial in the aspect of enhancing the teaching practices but also address moral problems of animal care (Odogwu et al., 2025), in the classroom. The teaching animal models are not only the models that portray the common factors in teaching, but also the evaluative domains of the student, diagnostic practice and surgery. This brings modernisation in teaching of veterinary schools (Animal Anatomical Teaching Models for Enhanced Veterinary Anatomy Education and Learning, 2025, p. 2). These new models involve the plastinated models, silicone models, and 3D-printed models and virtual simulations which are easier to learn than the previous method of teaching anatomy by dissection (Animal Anatomical Teaching Models for Enhanced Veterinary Anatomy Education and Learning, 2025, p. 19). Nonetheless, the predominance of such high technology is usually impeded by grievous issues including the cost of installing is very high, faculty and staff should possess specialised technical skills to be able to use it reasonably and appropriately maintain as well (Animal Anatomical Teaching Models for Enhanced Veterinary Anatomy Education and Learning 2025, p. 17). The other significant issue is that the uniform methods of quantifying the learning results that were completed with the help of all these multiple digital platforms are extremely diverse as the means of achieving it have changed radically by that point (Telecan et al., 2025). These high level anatomy models have an important impact on their development, application as well as their further use in terms of the institutional support, the educational impact and the economic impact (Animal Anatomy Teaching Models to promote veterinary anatomy education and learning, 2025, p. 17). Although this has occurred, the use of cadavers in veterinary schools is not low since its application has been going on in the anatomy and clinical skills laboratories. It implies that more creative education technologies will not be requested to minimize or eliminate its use (Varner et al., 2021). The switch of alternatives is determined by such ethical questions regarding the manner in which animals are treated because the conventional dissection in the procedures includes the usage of the living animal or cadavers, which cast doubt on their humane approach and suitability in the scenario that alternative humane simulations may be obtained (Moraes et al., 2024). Animal simulators, in their

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turn, which are animal-free and set in skills laboratories fulfill the principles of replacement, reduction, and refinement that offer the trainees animal-free alternatives to learn the necessary critical skills in the clinic before they can work with living animals (Veenema et al., 2024).

CONCLUSION

The research demonstrates that the introduction of the virtual reality and simulation based technology in teaching anatomy in veterinarian is an enormous change in the contemporary teaching process. The findings of the experiments confirm the fact that the existence of immersive learning environment can have a large degree of benefit to the students in the form of anatomical knowledge, spatial awareness, and academic performance in general with the help of the traditional way of teaching. There were significant, better assessment grade assessment, normalised learning and performance improvement at a task, as shown in the quantitative results, and qualitative evidence of that the learners were more interested and inspired and felt more relevant to clinical practice in the future. The use of three dimension interactive models was also significant because it helped the students to have a greater visualization of complex linkage in the anatomy. This remedied the decades-long access to the two-dimensional resources and access to a limited number of cadavers. The fact that the light learning load applied to the VR based systems does not overload the systems, attests to the fact that the immersive technology can be used to enable people to learn much without it making them feel overworked. Its balance between difficulty and cognition is the best. In addition to that, the findings provide evidence of the ethical and practical advantage of the extended reality technologies, specifically, the potential to reduce the use of live animal models and cadavers without a negative effect on the realism of the instructions. The aspect of VR resource scalability and reusability also highlights the possibility of minimizing inequities in the training infrastructure, specifically in the aspect of poorly-resourced ones, including in the educational ones. All this evidence goes to show that virtual reality is not just a tool of convenience but a game-changer pedagogical tool that can be adopted to not only, make veterinary education more competency-based, but, also, learner-centred. The use of immersive technologies offers better preparedness of veterinary students to solve problematic clinical cases because the technologies promote active learning, spatial awareness, and will allow students to practice it safely and repeatedly. The paper recommends that the application of the virtual reality and simulation within the veterinary training should be structured as a long term, productive and morally effective approach to teaching anatomy in the modern society.

REFERENCES

Aiyan, A. A. (2025). Enhancing Veterinary Anatomy Education Outcomes through a Multimodal, Student-Centered Approach. International Journal of Learning Teaching and Educational Research, 24(6), 142.

Al-Hor, M., Almahdi, H., Al-Theyab, M., Mustafa, A., Ahmed, M. S., & Zaqout, S. (2024). Exploring student perceptions on virtual reality in anatomy education: insights on enjoyment, effectiveness, and preferences. BMC Medical Education, 24(1), 1405.

Animal Anatomical Teaching Models for Enhanced Veterinary Anatomy Education and Learning. (2025). Pakistan Veterinary Journal.

Arif, L. S., Kusumoningrum, D. A., Pujitresnani, A., Rahadiani, P., Soemantri, D., Yusuf, P. A.,

Copyright©2025. This work is licensed under a Creative Common Attribution 4.0 International License. (cc by 4.0)
THE LUMINARY LEARNING INSTITUTE (SMC-PRIVATE) LIMITED

& Kekalih, A. (2024). Indonesian Medical Lecturers' and Students' Awareness, Perception, and Readiness Towards Extended Reality in Medical Education. Education in Medicine Journal, 16(2), 85.

Asoodar, M., Janesarvatan, F., Yu, H., & Jong, N. de. (2024). Theoretical foundations and implications of augmented reality, virtual reality, and mixed reality for immersive learning in health professions education. Advances in Simulation, 9(1), 36.

Baptista, C. S., Oliveira, P., & Ribeiro, L. (2023). An Exploratory Study of Students' Perceptions on the Use of Animals in Medical and Veterinary Medical Undergraduate Education. Journal of Academic Ethics, 22(1), 115.

Brito, C. de, Redondo, J. I., Tadeo, I., Bataller, E., García-Roselló, M., Madoz, I. C., & Terrado, J. (2025). Integrating artificial intelligence into veterinary education: student perspectives. Frontiers in Veterinary Science, 12, 1641685.

Choi, D. H., Choi, S. Y., Ahn, S. H., Lee, R., Cho, S. H., & Han, S. H. (2024). Development and Utilization of 3D Anatomy Education Content using Metaverse and XR for Remote Telemedicine Education. bioRxiv (Cold Spring Harbor Laboratory).

Curran, V., Xu, X., Aydin, M. Y., & Meruvia-Pastor, O. (2022). Use of Extended Reality in Medical Education: An Integrative Review [Review of Use of Extended Reality in Medical Education: An Integrative Review]. Medical Science Educator, 33(1), 275. Springer Science+Business Media.

Duarte, D. M., Barros, A. de M. C. de, Godoy, V. M. R. de, & Corrêa, R. R. (2023). Caracterização dos graduandos em medicina veterinária, quanto a fatores sociais, econômicos, crenças e traumas, e suas relações com o processo de ensino aprendizagem. Educação Online, 18(42).

Durrani, Z., Penrose, F., Anderson, J., Ricci, E., Carr, S., & Ressel, L. (2024). A complete workflow from embalmed specimens to life-like 3D virtual models for veterinary anatomy teaching. Journal of Anatomy.

Esmaeeli, E., Soleimani, A., Khorashadizadeh, M. S., Shahmoradi, L., Nekoonam, S., & Rezayi, S. (2025). A practical framework for developing a virtual reality-based anatomy education application: key content and technical requirements. Scientific Reports, 15(1), 12536.

Gómez, O., García-Manzanares, M., Chicharro, D., Juárez, M., Llamazares-Martín, C., Soriano, E. R., & Terrado, J. (2023). Application of Blended Learning to Veterinary Gross Anatomy Practical Sessions: Students' Perceptions of Their Learning Experience and Academic Outcomes. Animals, 13(10), 1666.

Herur-Raman, A., Almeida, N. D., Greenleaf, W., Williams, D., Karshenas, A., & Sherman, J. H. (2021). Next-Generation Simulation—Integrating Extended Reality Technology Into Medical Education. Frontiers in Virtual Reality, 2.

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THE LUMINARY LEARNING INSTITUTE (SMC-PRIVATE) LIMITED

Hooper, S. E., Washburn, E. H., Zayas, R., & Ronzani, D. (2023). Veterinary students leading research in veterinary education, diversity, and data analytics. Journal of the American Veterinary Medical Association, 262(1), 142.

Irabor, T.-J., Yonga, C. N., Danfakha, M., Hornick, J., Marlier, D., & Antoine-Moussiaux, N. (2025). Bridging theory and practice: a facilitation-driven game for reflective, collaborative veterinary education. Irish Veterinary Journal, 78(1).

Jallad, S. T., Natsheh, I., Helo, L. A., Ibdah, D. M., Salah, A., Muhsen, R., Shehadeh, Y., & Froukh, N. (2024). Nursing student's perceptions, satisfaction, and knowledge toward utilizing immersive virtual reality application in human anatomy course: quasi-experimental. BMC Nursing, 23(1).

Kanwischer, M., Tipold, A., & Schaper, E. (2024). Veterinary teaching in COVID-19 times: perspectives of university teaching staff. Frontiers in Veterinary Science, 11.

Li, M., Wang, X., Du, Y., Zhang, H., & Liao, B. (2025). Based on digital intelligence: teaching innovation and practice of veterinary internal medicine in China's southwest frontier [Review of Based on digital intelligence: teaching innovation and practice of veterinary internal medicine in China's southwest frontier]. Frontiers in Veterinary Science, 12, 1651179. Frontiers Media.

Li, X., Elnagar, D. W., Song, G., & Ghannam, R. (2024). Advancing Medical Education Using Virtual and Augmented Reality in Low- and Middle-Income Countries: A Systematic and Critical Review. Virtual Worlds, 3(3), 384.

Magrum, S. M., Bird, J., & Snow, E. L. (2025). Using emoji to ascertain student emotional responses to technology-based human anatomy instruction. Frontiers in Education, 10.

Mathiessen, H., Marana, M. H., Hénard, C., Nintemann, S. J., Gelskov, S. V., & Jørgensen, L. von G. (2023). Host-parasite interactions: Innate immune responses of zebrafish (Danio rerio) and immune evasive behaviour of a fish parasite. Research Portal Denmark.

Moraes, P. L., Ghisi, L., Barros, A. J. B. P. D., Peixoto, V. H. de C., Népoli, P. E. B., Colodel, É. M., Lima, L. F. S. de, & Souza, R. L. de. (2024). SimuVet: a preliminary study of the innovative development of a simulator for epidural anesthesia training in dogs. Frontiers in Veterinary Science, 11, 1322871.

Muca, E., Cavallini, D., Odore, R., Baratta, M., Bergero, D., & Valle, E. (2022). Are Veterinary Students Using Technologies and Online Learning Resources for Didactic Training? A Mini-Meta Analysis. Education Sciences, 12(8), 573.

Niu, S., Zhang, J., Jiang, L., Wang, B., & Yan, J. (2025). Enhancing anatomy education with virtual reality: integrating three-

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THE LUMINARY LEARNING INSTITUTE (SMC-PRIVATE) LIMITED

dimensional models for improved learning efficiency and student satisfaction [Review of Enhancing anatomy education with virtual reality: integrating three-dimensional models for improved learning efficiency and student satisfaction]. Frontiers in Medicine, 12, 1555053. Frontiers Media.

Odogwu, T. S., Mohamed, E. Y., Mishu, L. S., & Umahi, I. (2025). Effect of Virtual Reality Simulation on Anatomy Learning Outcomes: A Systematic Review [Review of Effect of Virtual Reality Simulation on Anatomy Learning Outcomes: A Systematic Review]. Cureus, 17(4). Cureus, Inc.

Owolabi, J., Gardner, K., Agboola, R., Yesudas, R. R., & Shaw, J. H. (2025). Use of simulation for teaching biomedical sciences to undergraduate medical students- a scoping review [Review of Use of simulation for teaching biomedical sciences to undergraduate medical students- a scoping review]. BMC Medical Education, 25(1). BioMed Central.

Schirone, R., Corte, G. M., Ehlers, J. P., Herre, C., Schmedding, M., Merle, R., Pachtmann, J., & Bahramsoltani, M. (2024). Effects of 3D Scans on Veterinary Students' Learning Outcomes Compared to Traditional 2D Images in Anatomy Classes. Animals, 14(15), 2171.

Sharmin, N., Chow, A., & King, S. (2023). Effect of teaching tools in spatial understanding in health science education: a systematic review [Review of Effect of teaching tools in spatial understanding in health science education: a systematic review]. Canadian Medical Education Journal. Canadian Medical Education Journal.

Singer, L., Evans, L., Zahra, D., Agbeja, I., & Moyes, S. (2024). Fostering engagement in virtual anatomy learning for healthcare students. BMC Medical Education, 24(1), 414.

Telecan, T., Capraș, R.-D., Filip, G. A., Bonea, M., & Crivii, C. (2025). Dissection in the 21st century: virtual tables versus traditional methods and their influence on medical students' perception – a systematic review [Review of Dissection in the 21st century: virtual tables versus traditional methods and their influence on medical students' perception – a systematic review]. BMC Medical Education, 25(1), 1332. BioMed Central.

Varner, C., Dixon, L., & Simons, M. C. (2021). The Past, Present, and Future: A Discussion of Cadaver Use in Medical and Veterinary Education [Review of The Past, Present, and Future: A Discussion of Cadaver Use in Medical and Veterinary Education]. Frontiers in Veterinary Science, 8. Frontiers Media.

Veenema, N. J., Hierck, B. P., Bok, H. G. J., & Salvatori, D. (2024). Links between learning goals, learning activities, and learning outcomes in simulation-based clinical skills training: a systematic review of the veterinary literature [Review of Links between learning goals, learning activities, and learning outcomes in

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simulation-based clinical skills training: a systematic review of the veterinary literature]. Frontiers in Veterinary Science, 11, 1463642. Frontiers Media.

Wang, C., Yin, T., Ma, K., Shyu, J., Cheng, C.-P., Huang, Y.-L., & Chiang, M. (2022). Sex Differences in Students' Performance in VR-based Learning of Gross Anatomical Education. Research Square (Research Square).

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