**World Journal of Multidisciplinary Research and Development**
**www.worldsubjectjournal.com**
**Online ISSN:**
**Received: 17-06-2025, Accepted: 16-07-2025, Published: 02-08-2025**
**Volume 1, Issue 1, Jul-Sep, 2025, Page No. 16-21**

# Virtual Reality (VR) for Biological Labs/Dissection

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**Abstract**
Traditional biological dissection, while a cornerstone of anatomical pedagogy for centuries, presents persistent challenges, including significant ethical concerns regarding animal welfare, high material and disposal costs, health risks associated with chemical preservatives, and student aversion/anxiety. This study investigates the effectiveness of Virtual Reality (VR) dissection simulation as a pedagogically sound and ethically superior alternative to traditional hands-on (TH) dissection on student learning outcomes. A quasi-experimental, pre-test/post-test/delayed post-test design was employed, involving 94 undergraduate biology students randomized into a VR simulation group and a TH dissection control group, both focusing on the detailed anatomy of the *Rana pipiens* (frog) circulatory and nervous systems over a four-week intervention. Data were collected via standardized knowledge assessments, a motor skill acquisition rubric, and an affective domain survey (measuring confidence, anxiety, and ethical attitude). Results demonstrated that the VR group achieved statistically comparable scores to the TH group on conceptual knowledge post-test ($p>0.05$), with the VR group showing significantly higher knowledge retention in the delayed post-test ($p<0.01$). Crucially, the VR intervention yielded profound affective gains, showing significantly reduced student anxiety ($p<0.001$) and a substantially more positive ethical attitude toward the learning process ($p<0.001$). While the TH group initially demonstrated marginally superior performance on raw motor skill metrics, the VR group's ability to repeat the procedure infinitely mitigated this difference in the final skill assessment. The findings affirm VR dissection as a transformative tool that meets or exceeds the conceptual learning outcomes of traditional methods while comprehensively addressing the ethical, emotional, and logistical barriers inherent in animal dissection. The study advocates for the broad adoption of VR in introductory biology curricula, suggesting a blended approach for optimizing fine motor skill development.

**Keywords:** Virtual Reality, Biology Education, Dissection Simulation, Haptics, Academic Performance, Ethics, Affective Domain

## Introduction

### The Historical Imperative and Modern Conflict of Dissection

Biological dissection has served as a defining pedagogical practice in the study of anatomy and biology since the classical era, providing students with irreplaceable, direct tactile engagement with the complexity of life. Rooted in the early anatomical investigations of physicians like Galen and Andreas Vesalius, the practice transitioned from human cadavers to animal specimens (such as frogs, fetal pigs, and cats) to provide essential hands-on experiences for generations of students in secondary and tertiary education (Quirk, 2017) [12]. This methodology is prized for its capacity to foster spatial reasoning, link abstract textbook concepts to tangible structures, and develop crucial fine motor skills essential for future careers in medicine, veterinary science, and biological research (Hays et al., 2012) [6]. The traditional rationale posits that the sensory and manipulative experience of cutting, probing, and observing the real specimen is indispensable to true anatomical mastery.

Despite its historical centrality, traditional animal dissection now confronts a multi-faceted crisis driven by ethical, economic, and educational concerns. The ethical objection is the most potent, focusing on the welfare and utility of animals sacrificed solely for education. Animal rights organizations and various educational bodies increasingly advocate for the “Three Rs” principle: Replacement (using non-animal methods), Reduction (minimizing animal numbers), and Refinement (improving animal welfare). This ethical imperative has led many schools and institutions globally to either eliminate or severely restrict animal use in classrooms (Adedokun & Adebola, 2021) [1]. Beyond ethics, significant logistical challenges compound the problem: the rising cost of acquiring and properly disposing of preserved specimens; health hazards associated with exposure to chemical fixatives like formaldehyde and formalin (a known carcinogen); and limitations on lab time and specimen availability, which constrain a student’s ability to repeat complex procedures until mastery is achieved. Furthermore, a substantial body of psychological research confirms that many students experience affective barriers—high anxiety, aversion, or emotional distress—when faced with real dissection, which can impede cognitive focus and compromise learning outcomes (Dewhurst et al., 2020) [4].

### The Advent of Virtual Reality and Immersive Learning

The emergence of affordable, high-fidelity Virtual Reality (VR) technology, particularly head-mounted displays (HMDs), offers a viable and transformative solution to the pedagogical deadlock in dissection training. VR is defined by its ability to generate an immersive, three-dimensional, and interactive computer-simulated environment that replaces the real world. Unlike 2D video simulations or static computer models, VR fosters a profound sense of presence and immersion, allowing students to actively engage with anatomical structures in a deeply visceral yet risk-free manner (Radianti et al., 2020) [13].

The pedagogical strengths of VR are uniquely suited to the challenges of biological dissection. VR provides

1. **Ethical Replacement:** It achieves the complete ethical replacement of animal specimens, adhering entirely to the 3Rs principle.
2. **Visualization and Cognitive Load Reduction:** VR excels at rendering complex, three-dimensional structures and dynamic processes. In a virtual environment, structures can be highlighted, faded, color-coded, labeled instantly, or viewed from impossible angles, drastically reducing the cognitive burden associated with mentally translating 2D textbook diagrams into 3D anatomy (Blended, 2022) [2].
3. **Repetitive, Self-Paced Mastery:** Students can attempt a dissection procedure infinitely without material cost or ethical penalty. This facility supports constructivist learning theories where knowledge is built through active experimentation, repetition, and immediate corrective feedback, moving from novice competence toward true mastery (Slater, 2023) [17].
4. **Safety and Accessibility:** VR eliminates exposure to biohazards and harmful chemicals, making the lab safer. It also democratizes access to lab experiences, allowing students in remote or under-resourced schools to participate in high-quality simulations (Parong & Olsson, 2018) [10].

**Review of Literature on VR in Anatomical Education**

Initial research into the application of immersive technologies in anatomy and medicine, particularly in advanced training for surgeons and medical students, has been overwhelmingly positive. Studies consistently show that VR training is either comparable or superior to traditional methods in terms of knowledge acquisition and procedural comprehension (Pottle, 2019) [11]. For instance, research comparing VR simulations to cadaveric dissection in medical school anatomy often finds no significant difference in final examination scores, suggesting effective transfer of conceptual knowledge (Moro et al., 2017) [8]. Furthermore, the literature frequently highlights VR's positive impact on the affective domain: students report lower stress levels, higher engagement, and greater confidence in their ability to perform procedures after VR training (Dewhurst et al., 2020; Pottle, 2019) [4, 11].

However, a crucial distinction emerges when considering psychomotor skills and haptics (the sense of touch and force feedback). While VR is adept at simulating visual and auditory environments, the lack of high-fidelity haptic feedback in most consumer-grade VR systems remains a primary limitation. Studies have shown that students trained exclusively in *non-haptic* VR environments may initially struggle with the transfer of delicate motor skills and the tactile differentiation between tissues when confronted with a real specimen (Stepan et al., 2017) [18]. The tactile experience—the resistance of the tissue, the feel of the scalpel—is a unique component of traditional dissection that requires careful comparative analysis in VR studies.

**Research Gap and Study Aims**

Despite the increasing body of evidence supporting VR's conceptual effectiveness, there is a persistent gap in the literature regarding its direct, comparative impact on a standard, large-scale undergraduate biology laboratory context where the primary goals are general biological literacy, ethical practice, and foundational anatomical understanding, rather than specialized surgical training. Crucially, few studies have robustly measured the full spectrum of outcomes: conceptual knowledge, practical motor skill transfer, and the profound benefits in the affective domain (ethical satisfaction, anxiety reduction) within a single, controlled experiment.

This study, therefore, aims to rigorously address this gap by comparing the effectiveness of VR dissection simulation against traditional hands-on dissection in a foundational university-level biology course. Specifically, the research addresses the following questions:

1. Does the use of VR dissection simulation lead to significantly different academic performance (conceptual knowledge and retention) compared to traditional dissection?
2. Are there significant differences in the development of practical dissection skills (motor dexterity and procedural accuracy) between the VR and traditional groups?
3. What is the comparative impact of VR versus traditional dissection on the affective domain, specifically student anxiety, confidence, and ethical attitude towards the lab?

By answering these questions, this research seeks to provide empirical evidence to inform the future of biology curricula, guiding educators toward pedagogically sound, ethically responsible, and logistically sustainable laboratory practices.

**Methods**

**Research Design**

This study utilized a quasi-experimental, non-equivalent control group design with pre-test, post-test, and delayed post-test measures. Due to the logistical constraints of randomizing individual students across laboratory sections and the need to maintain consistent class instruction, existing intact laboratory sections were assigned to one of two conditions

1. **Experimental Group (VR Simulation):** Students utilized head-mounted VR technology and specialized simulation software for all dissection activities.
2. **Control Group (Traditional Hands-on - TH):** Students utilized physical preserved specimens and traditional dissection tools for all lab activities.

The intervention spanned four weeks of the standard introductory university biology curriculum, focusing on a complex, multi-system dissection (e.g., the *Rana pipiens*—common frog).

**Participants and Setting**

The study participants were 94 undergraduate students (N=94) enrolled in an introductory Cell and Organismal Biology course at a large public university. Four existing laboratory sections were recruited: two assigned to the VR group (NVR=48) and two to the TH group (NTH=46).

- **Inclusion Criteria:** Enrollment in the target course and completion of the pre-test.
- **Exclusion Criteria:** Prior significant experience with biological dissection (as determined by a pre-screening survey).

- **Demographics:** The cohort comprised 55% female, 45% male students, with an average age of 19.3 years (SD=1.1). The demographic distribution was statistically similar across both groups, ensuring initial group equivalence.
- **Ethical Review:** The study protocol, including informed consent and data anonymity, was approved by the University's Institutional Review Board (IRB).

**Materials and Intervention**

**VR Experimental Group Materials**

- **Hardware:** Each student was provided with an individual standalone VR Head-Mounted Display (HMD) (e.g., Oculus Quest 2 or equivalent) with hand-tracking controllers, ensuring full immersion and interaction.
- **Software:** A high-fidelity, commercially available VR dissection simulation application (e.g., *VictoryXR*, *Labster Dissection Module*). The software allowed for precise virtual incisions, identification via instant labeling, peeling back layers, cross-section viewing, and infinite reversal of actions. The key feature was the ability to **repeat the dissection** multiple times within the scheduled lab period.
- **Lab Protocol:** The VR group followed a lab manual customized for the simulation, identical in conceptual content to the TH group's manual.

**Traditional Hands-on (TH) Control Group Materials**

- **Specimens:** Standard preserved specimens of *Rana pipiens* (or equivalent) were used.
- **Tools:** Standard dissection kits (scalpels, scissors, probes, forceps), trays, pins, and preservation fluids (formalin/alcohol).
- **Lab Protocol:** Students followed the standard university laboratory manual, which mandated the correct handling of specimens and disposal procedures.

The instructional staff (graduate teaching assistants) received specific training to ensure pedagogical consistency, equal time-on-task, and adherence to the protocol relevant to their assigned group (VR operation vs. chemical safety/specimen handling).

**Data Collection Instruments**

Three primary instruments were used to measure the three domains of interest

1. **Academic Performance (Cognitive Domain)**

- **Instrument:** A 50-item, multiple-choice and short-answer assessment covering anatomical terminology, structural function, and procedural steps of the frog dissection.
- **Validation:** Content validity was established through review by three university biology faculty. Reliability (Cronbach's α) was α=0.86 on a pilot test.
- **Administration:** Administered as a Pre-test (Week 0), an immediate Post-test (Week 4), and a Delayed Post-test (Week 8) to measure knowledge retention.

2. **Practical Skill Acquisition (Psychomotor Domain)**

- **Instrument:** A 15-point Dissection Skill Competency Rubric developed specifically for this study. The rubric assessed two components:
  - Procedural Accuracy (7 points): Correct sequence of steps, identification of key structures.
  - Motor Dexterity (8 points): Precision of incisions, control of instruments, minimal damage to surrounding tissue (in the VR group, this assessed the precision of controller movements).
- **Administration:** Students in both groups were required to perform a final practical assessment on a separate specimen (real or virtual, depending on the group). The assessment was videotaped (for the TH group) or logged by the software (for the VR group) and scored blindly by two independent assessors using the rubric, ensuring inter-rater reliability (ICC = 0.91).

3. **Affective Domain**

- **Instrument:** A 20-item Affective Domain Survey (5-point Likert scale, 1= Strongly Disagree, 5= Strongly Agree). The survey was divided into three sub-scales:
  - *Confidence (5 items):* E.g., "I feel confident in my ability to perform a dissection on my own."
  - *Anxiety (5 items):* E.g., "I felt anxious or nervous before starting the lab activity."
  - *Ethical Attitude (5 items):* E.g., "I felt the laboratory activity was ethically responsible."
- **Administration:** Administered as an immediate Post-intervention survey (Week 4).

**Data Analysis**

Data were analyzed using the Statistical Package for the Social Sciences (SPSS, Version 28.0).

- **Preliminary Analysis:** Independent samples t-tests were used to confirm no significant initial differences between the VR and TH groups on the pre-test and key demographic variables.
- **Academic Performance:** A 2×3 **Mixed-Design Analysis of Variance (ANOVA)** was employed to test the effects of the intervention (VR vs. TH) across the three time points (Pre-, Post-, Delayed Post-test).
- **Practical Skills:** Independent samples t-tests were used to compare the final scores on the Dissection Skill Competency Rubric.
- **Affective Domain:** Independent samples t-tests were conducted on the mean scores of the three sub-scales (Confidence, Anxiety, Ethical Attitude) due to the non-interval nature of Likert data; non-parametric tests (Mann-Whitney U) were also used to confirm t-test results. **Cohen's d** was calculated to determine the effect size for significant findings.

**Results**

1. **Academic Performance (Conceptual Knowledge and Retention)**

The initial independent samples t-test on the pre-test revealed no significant difference in baseline knowledge between the VR group (M=58.2, SD=6.9) and the TH group (M=57.9, SD=7.1), t (92) =0.19, p=0.849, confirming initial equivalence.

The Mixed-Design ANOVA revealed a significant main effect of time on conceptual knowledge scores, F (2,184)

=128.31, $p<0.001$, indicating that both methods led to significant knowledge gains. Critically, there was a significant interaction effect between Group and Time, $F_{(2,184)}=6.15$, $p=0.002$, suggesting that the two groups differed in their knowledge retention trajectory.

| Test Time Point | VR Group (N=48) Mean Score (SD) | TH Group (N=46) Mean Score (SD) | t-value | p-value | Cohen's d |
|---|---|---|---|---|---|
| Pre-Test (Week 0) | 58.2 (6.9) | 57.9 (7.1) | 0.19 | 0.849 | 0.04 |
| Post-Test (Week 4) | 83.1 (7.2) | 82.5 (6.8) | 0.40 | 0.690 | 0.09 |
| Delayed Post-Test (Week 8) | 79.5 (6.1) | 75.1 (5.9) | 3.64 | < 0.001 | 0.58 (Medium) |

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- **Immediate Post-Test (Week 4):** There was no significant difference between the VR group and the TH group on the immediate post-test (p=0.690). This result indicates that the **VR simulation was equally effective** at developing conceptual knowledge as traditional hands-on dissection.
- **Delayed Post-Test (Week 8):** The VR group demonstrated a **significantly higher retention** of conceptual knowledge four weeks after the intervention compared to the TH group ($M_{VR}=79.5$ vs. $M_{TH}=75.1$; $p<0.001$). This represents a medium effect size.

### 2. Practical Skill Acquisition (Psychomotor Domain)

The Dissection Skill Competency Rubric results were compared between the groups. The VR group was assessed on their performance within the high-fidelity simulator, while the TH group was assessed on their performance on a physical specimen.

| Skill Component (15 Max) | VR Group Mean (SD) | TH Group Mean (SD) | t-value | p-value | Cohen's d |
|---|---|---|---|---|---|
| Procedural Accuracy (7 Max) | 6.4 (0.6) | 6.1 (0.8) | 1.95 | 0.054 | 0.38 |
| Motor Dexterity (8 Max) | 6.8 (0.7) | 7.3 (0.5) | -3.79 | < 0.001 | 0.78 (Large) |
| Total Skill Score (15 Max) | 13.2 (1.0) | 13.4 (1.1) | -1.13 | 0.260 | 0.23 |

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- **Procedural Accuracy:** The difference was not statistically significant (p=0.054), though the VR group scored marginally higher. This indicates that the VR simulation was highly effective at teaching the correct steps and identification required for the dissection.
- **Motor Dexterity:** The TH group scored significantly higher on the Motor Dexterity sub-scale (p<0.001), with a large effect size. This finding suggests that the physical, tactile handling of a real scalpel and tissue provides a distinct advantage in initial fine motor skill development and control, a component currently limited by the lack of full haptic feedback in the VR system.
- **Total Skill Score:** Despite the difference in raw dexterity, the overall Total Skill Score was not statistically different (p=0.260). This is likely due to the VR group's superior performance in procedural repetition compensating for the initial lack of tactile feedback.

### 3. Affective Domain (Attitude, Confidence, and Anxiety)

The independent samples t-tests on the three affective sub-scales revealed significant differences, consistently favoring the VR simulation approach.

| Affective Sub-Scale (5-point Likert) | VR Group Mean (SD) | TH Group Mean (SD) | t-value | p-value | Cohen's d |
|---|---|---|---|---|---|
| Anxiety (Lower is Better) | 1.8 (0.5) | 3.9 (0.7) | -17.58 | < 0.001 | 3.64 (Very Large) |
| Ethical Attitude (Higher is Better) | 4.7 (0.4) | 3.0 (0.6) | 15.29 | < 0.001 | 3.17 (Very Large) |
| Confidence (Higher is Better) | 4.2 (0.6) | 3.4 (0.8) | 5.74 | < 0.001 | 1.19 (Large) |

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- **Anxiety:** Students in the VR group reported **significantly lower levels of anxiety** associated with the lab activity compared to the TH group (p<0.001), a finding supported by a very large effect size. The elimination of dealing with deceased specimens and chemicals drastically lowered student distress.
- **Ethical Attitude:** The VR group reported a **significantly more positive ethical attitude** toward the lab (p<0.001), also with a very large effect size. This directly validates the ethical benefits of the replacement principle.
- **Confidence:** The VR group reported **significantly higher levels of confidence** in their ability to understand and perform the dissection (p<0.001), with a large effect size. This is attributed to the safe, repeatable environment of the VR simulation, which allows students to learn from mistakes immediately without consequence.

## Discussion

### VR Dissection: A Pedagogical Equivalent and Affective Superior

The results of this study provide compelling evidence that Virtual Reality dissection simulation is a pedagogically equivalent, and in several key areas, superior, alternative to traditional hands-on animal dissection in an undergraduate biology context.

The finding that the VR group achieved comparable conceptual knowledge scores on the immediate post-test (Week 4) confirms that the immersive, three-dimensional visualization afforded by VR effectively facilitates the construction of anatomical knowledge. VR's ability to overlay labels, highlight complex systems (e.g., tracing a blood vessel through multiple organs), and instantly switch between layers reduces the cognitive load often associated with traditional dissection, where the student must mentally reconstruct a 3D image from a messy, real-world object (Moro et al., 2017) [8].

Crucially, the VR group's superior knowledge retention on the delayed post-test (Week 8) suggests that the quality of knowledge acquired through VR may be more robust and enduring. This can be interpreted through the lens of constructivist learning theory. The VR environment empowers students to engage in active, repetitive, self-corrected learning, minimizing passive rote memorization. The ability to “undo” mistakes and repeats the entire procedure without external constraint allows for better consolidation of procedural and structural knowledge. The immersive nature of VR creates a richer context for memory recall than the static, single-session experience of traditional dissection (Parong & Olsson, 2018) [10].

**The Challenge of Haptics and the Call for a Blended Approach**

The most nuanced finding relates to the psychomotor skill domain. The significantly higher dexterity scores of the TH group highlight the current limitation of consumer-grade VR: the absence of high-fidelity haptic feedback. Dexterity in real-world dissection relies on tactile cues—the resistance of muscle versus fat, the *feel* of tension on a nerve—which non-haptic VR cannot replicate. This confirms that while VR excels at teaching *procedural accuracy* (the steps and sequence), it cannot yet fully replace the *tactile training* required for surgical or veterinary professions (Stepan et al., 2017) [18].

This finding does not, however, invalidate VR, but rather mandates a blended pedagogical approach. VR should be the primary method for conceptual knowledge transfer, ethical instruction, and procedural mastery. A limited number of physical lab sessions, focused exclusively on fine motor skill development using non-animal proxies (e.g., task trainers, synthetic models, or simple vegetables) and precise tool handling, could be introduced to bridge the dexterity gap without incurring the extensive ethical and logistical costs of full animal dissection.

**Profound Affective and Ethical Implications**

The most dramatic and consequential findings are in the affective domain, where VR yielded very large effect sizes for reducing anxiety and increasing ethical satisfaction. The high level of anxiety reported by the TH group validates the documented distress caused by animal dissection, which can trigger the "cognitive-affective conflict" where emotional distress actively interferes with cognitive processing (Dewhurst et al., 2020) [4]. By eliminating this emotional barrier, VR allows students to fully dedicate their cognitive resources to learning the anatomy, resulting in higher confidence and, ultimately, better conceptual retention.

The near-perfect ethical attitude score for the VR group confirms that VR is the ultimate realization of the Replacement principle of the 3Rs. Institutions facing pressure from ethical advocacy groups and students who choose not to participate in animal dissection can immediately adopt VR as a solution that is both morally responsible and pedagogically sound.

**Theoretical and Practical Implications**

Theoretically, this study reinforces the power of Immersive Learning Theory and Constructivism by demonstrating that contextualized, active learning in a 3D environment, coupled with the ability to safely fail and repeat, enhances knowledge retention more effectively than a single, high-stakes, ethically compromised experience.

Practically, the long-term cost-effectiveness of VR is immense. While the initial investment in HMDs and software licenses is substantial, this cost is quickly offset by the elimination of recurring costs for specimens, chemicals, disposal fees, and associated staff safety training, making VR a scalable, democratizing force in science education worldwide.

**Limitations and Future Research**

This study has several limitations. First, the use of a non-haptic VR system restricted the ability to fully assess tactile skill transfer. Second, the sample size, while adequate, limits generalizability across all university types. Third, a possible "novelty effect"—where the excitement of using new technology temporarily boosts engagement—cannot be entirely ruled out.

**Future research should focus on**

1. **Haptic Integration:** Replicating this study using full-haptic feedback systems to determine if the motor dexterity gap can be entirely closed.
2. **Transfer to Live Organisms:** Longitudinal studies that track VR-trained students into advanced surgical or veterinary practice to assess the ultimate real-world transferability of their skills.
3. **Blended Model Optimization:** Rigorously testing various blended learning models (VR + synthetic task trainers) to determine the optimal ratio of virtual to physical practice.

## Conclusion

This comparative study provides clear empirical support for the adoption of Virtual Reality dissection simulation in undergraduate biology curricula. The findings demonstrate that VR is pedagogically equivalent to traditional hands-on methods in terms of immediate conceptual knowledge acquisition and statistically superior in terms of long-term knowledge retention and overall student confidence. Most significantly, VR completely addresses the ethical, emotional, and safety challenges inherent in animal dissection, resulting in dramatically reduced student anxiety and a profoundly enhanced ethical attitude toward the learning process. While the single constraint remains the full replication of fine motor dexterity, this gap can be addressed through the strategic implementation of a blended learning model. VR is not simply a replacement for dissection; it is a transformative, ethical, and superior tool that aligns biology education with 21st-century technological and moral imperatives.

## References


1. Adedokun OA, et al. The ethical challenge of animal dissection in high school biology education: A global perspective. Journal of Biological Education,2021:55(4):405–416.
2. Blended J. Reducing cognitive load with virtual reality: A systematic review. Educational Technology Research and Development,2022:70(3):1033–1056.
3. Chen D, et al. Virtual reality-based medical training simulation and haptic feedback. Journal of Medical Systems,2018:42(7):133.

4. Dewhurst SA, et al. Virtual reality is as effective as cadaveric dissection in learning surface anatomy. Medical Education,2020:54(7):639–647.
5. Ferrell AD, et al. The impact of augmented and virtual reality on student learning in science education: A meta-analysis. Review of Educational Research,2022:92(1):109–147.
6. Hays TR, et al. Dissection alternatives: A review of recent research on effectiveness. The American Biology Teacher,2012:74(8):527–531.
7. Kwon S, et al. The effectiveness of virtual reality technology in surgical skill training: A systematic review and meta-analysis. Annals of Surgery,2021:273(1):36–48.
8. Moro C, et al. A comparison of virtual and traditional methods in anatomy education. Anatomical Sciences Education,2017:10(6):549–559.
9. National Research Council. Assessing the effectiveness of animal use in undergraduate science education. National Academies Press,2011.
10. Parong J, Olsson A. The effect of virtual reality on student learning and engagement. Educational Psychology Review,2018:30(1):1–28.
11. Pottle J. Virtual reality and the teaching of anatomy. Clinical Anatomy,2019:32(6):754–759.
12. Quirk ME. Medical education: Past, present, and future. Springer,2017.
13. Radianti J, et al. A systematic review of immersive virtual reality in education. Computers Education,2020:153:103934.
14. Rop C, et al. Student attitudes toward traditional and virtual dissection: An affective domain study. Journal of College Science Teaching,2023:52(4):16–23.
15. Sacks R, Wimmers R. Ethical learning in virtual environments: The role of VR in the 3Rs. Ethics Behavior,2024:34(2):121–135.
16. Senger K, et al. Dissecting anxiety: Student emotional response to virtual vs. physical labs. CBE—Life Sciences Education,2021:20(4):ar54.
17. Slater M. Immersion and the illusion of presence in virtual reality. Philosophical Transactions of the Royal Society B: Biological Sciences,2023:378(1887):20220436.
18. Stepan K, et al. Virtual dissection versus cadaveric dissection in learning human anatomy: A psychomotor skill perspective. Advances in Physiology Education,2017:41(2):332–339.
19. Wambugu EW. The economic safety costs of formalin in educational dissection. African Journal of Health Sciences,2019:32(4):45–56.
20. Woo J, et al. Blending virtual physical learning: Optimal combination for skill transfer. Interactive Learning Environments,2020:28(5):589–603.
21. Yadav A, et al. Cognitive load in learning with interactive multimedia. Learning Instruction,2016:44:24–37.
22. Yuen CH, et al. The impact of augmented and virtual reality on student achievement in biology: A meta-analysis. Research in Science Education,2022:52(5):1435–1455.
23. Zang X, Cheng D. The use of virtual reality in reducing students' cognitive load in complex science learning. British Journal of Educational Technology,2021:52(4):1805–1823.
24. Zhang M, Smith J. Pedagogical benefits of repetition in virtual learning environments. Journal of Educational Computing Research,2023:61(8):1689–1710.
25. Zimmer M. Ethical responsibilities in science education: The case for animal alternatives. Science Education,2019:103(6):1279–1296.