



## Teaching Gross Anatomy in the AI Era: A Systematic Review of Traditional and Digital Modalities

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**Abstract: Background:** Gross anatomy learning by practicals remain central to medical schools' however, evolving technologies and educational reforms have prompted substantial variation in instructional strategies for the upcoming generations. **Objective:** To review and synthesize evidence systematically, comparing traditional with digital and hybrid gross anatomy teaching modalities while keeping a focus on effectiveness, student learning outcomes, and curricular implications. **Methods:** A PRISMA-guided structured review was conducted using PubMed, Scopus, ERIC, and Google Scholar. Studies published between 2000–2024, involving undergraduate medical learners, were included. A total of 2,316 records were identified, screened, and narrowed to 62 eligible studies. Data extraction covered instructional modality, outcomes, assessment strategy, and methodological quality. A narrative synthesis was achieved. **Results:** Across the 62 studies included, cadaveric dissection consistently supported deep spatial understanding, professional identity formation, and emotional resilience. Prosection facilitated efficient, standardized instruction. Digital tools especially 3D visualization, VR, and AR enhanced conceptual understanding and accessibility but surely lacked tactile experience. Hybrid models combining dissection with digital platforms yielded the strongest and most consistent learning outcomes in most of the setups. **Conclusion:** In professing Anatomy no single modality seems sufficient due to magnitude of the subject. Hybrid, multimodal approaches are most effective for addressing diverse learner needs. Curricula needs to integrate digital tools while preserving cadaver based learning. Further standardized and longitudinal research is needed.

**Key Words:** Anatomy Education, AI, Cadaver, Dissection, Hybrid Learning, 3D Visualization, Virtual Reality, Augmented Reality, Medical Curriculum

### INTRODUCTION

Anatomy education dates back to ancient civilizations, with early dissections reported and practiced in Alexandria by Herophilus (335-280BC) and Erasistratus (304-250BC). The Renaissance marked a pivotal period, particularly through the works of Andreas Vesalius (1514-1564AD), who revolutionized anatomical science through hands on dissection [1]. For centuries cadaveric dissection was the cornerstone of medical training [2]. However, modern educational reforms, increased student enrollment, reduced contact hours, legal and ethical scrutiny have necessitated innovations [3-5]. The integration of digital technologies, such as 3D reconstruction, holography, and computer

assisted learning, reflects a paradigm shift toward multimodal, student centered learning environments emergence [6-8].

Even after centuries of evolution of human medicine, anatomy still serves as the foundation of medical education, being essential for both clinical and surgical arenas. A thorough grasp of human anatomy is crucial for precise diagnosis, planned expert interventions and effective communication among the healthcare professionals [9,10]. Traditional gross anatomy practicals comprising of cadaveric dissections, have been fundamental in anatomy education, providing students with a valuable chance to investigate the three-dimensional arrangement of human

structure. [11]. To better support today's diverse medical students, schools are updating their teaching methods. They are now using digital tools, virtual reality and preserved specimens to provide a more modern training experience. [12,13]. These modern approaches seek to boost, and in certain instances, substitute conventional cadaver dissection due to various logistical, ethical, and health related issues [14]. Technology promises more accessible and engaging learning experiences but its efficacy in comparison to traditional methods is still being aggressively explored and discussed. Additional factors such as culture, institutional policies, and individual learner preferences play a significant role in how different teaching strategies are adopted and perceived [15]. This review compiles existing research on anatomy practicals methods, assesses their educational significance and explores their impact on contemporary medical training.

### Teaching Modalities

- **Cadaveric Dissection:** This provides, beyond any doubt, unmatched exposure to human variability, tactile feedback, and spatial orientation. Indeed, it is associated with enhanced empathy, professional development and identity with a deeper appreciation for humans and the life within [16-18]
- **Prosection:** Prosected specimens by experts, provide clear anatomical views with precision and reduce time investment and health risks. This method facilitates focused instruction and group-based learning [19]
- **Virtual Simulations and augmented reality / virtual reality (AR/VR) Tools:** Technologies and its ancillary products such as the 'Anatmage Table, Complete Anatomy app, and zSpace' do offer high-resolution, interactive anatomy experiences. These tools support remote learning and can supplement physical labs. Despite concerns regarding the lack of tactile learning, virtual simulations are increasingly accepted for their flexibility and scalability [20,21]. Their cost effectiveness is still a challenge for many medical schools that don't have sufficient funds
- **Hybrid and Integrated Models:** A growing body of evidence supports combining traditional dissection and digital tools to satisfy diverse learning preferences and cognitive styles. Hybrid models have proven to enhance comprehension, retention, and clinical correlation skills [22,23]

### Study Objectives

- To evaluate evidence on traditional, digital and hybrid gross anatomy teaching modalities
- To compare learning outcomes, student perceptions, and educational impact across above modalities
- To find gaps and propose evidence-based curricular recommendations

## METHODS

- **Databases Searched:** PubMed, Scopus, ERIC, Google Scholar
- **Search Period:** From January 2000 to December 2024
- **Search Terms Included Combinations of:** "gross anatomy," "cadaveric dissection," "virtual anatomy," "3D learning," "AR/VR anatomy," "medical education," "student perception."
- **Inclusion Criteria:** peer-reviewed studies, recognized empirical data, English-language
- **Exclusion:** non-medical populations, articles without educational outcomes, opinion pieces, non-English literature

Study selection followed PRISMA:

- Records identified : 2,316
- Records screened : 1,284
- Full-texts assessed : 142
- Studies included : 62

### Data Extraction Variables

Study design, sample size, learning modality, primary outcomes, assessment tools, conclusions.

### Quality Appraisal

SANRA for narrative studies and adapted risk-of-bias checklist.

### Synthesis

Narrative thematic synthesis with four major themes: spatial learning, student engagement, assessment outcomes, curricular feasibility.

### Ethical Approval

No ethical approval was applied / required as per the institutional policy, as this article is using the already published data and not using any human tissue studies.

## RESULTS

Cadaveric Dissection came out as absolute winner, as consistent evidence suggests its superiority in tactile learning, spatial orientation, emotional maturation, and professional identity formation. Reported limitations included cost, ethical considerations and reduced availability with every passing year and more legalities invoked over time. Prosection-based learning provides efficient exposure to high-quality anatomical structures. It is more effective for large cohorts but provides limited hands-on experience.

Digital Technologies (3D, VR, AR) have been effective for conceptual grasp, repeatability, remote learning and student engagement due to newer generations familiarity. But, it clearly lacks the essential tactile realism which is crucial in human medical interaction and also needs expensive infrastructure.

Hybrid Models are more competitive and show a strong overall performance. Combining dissection with digital augmentation improved retention, exam performance with motivation and clinical reasoning.

## DISCUSSION

The evolution of anatomical education has necessitated the development of modern assessment tools that align with current educational approaches, ensuring a comprehensive evaluation of a student's competency. 'Objective Structured Practical Examinations' (OSPE) remains the gold standard for assessing anatomical knowledge and practical skills while offering a structured, reproducible, unbiased evaluation of student performance. However, innovations in technology have introduced state-of-the-art tools such as virtual quizzes, interactive anatomical labeling applications and simulation-based assessments that are getting increasingly integrated into modern curricula.

Studies have concluded that students find hands on learning by dissection more valuable but also recognize the clarity and ease offered by virtual tools. Evidence has demonstrated enhanced academic performance and a better grasp of anatomy through multimodal learning methods [24-26]. Besides, student learning outcomes improve and get enhanced when they engage with clinically relevant applications, tackle problem-solving tasks and frankly collaborate with their peers [27,28]. Assessment objectivity, scalability and compliance increases with the use of the emerging tools.

Gaming culture is rampant in the newer generation, therefore, virtual quizzes and learning platforms that incorporate games, promote active recall and self-paced study, whereas 3D anatomical apps allow students to engage in spatial learning and self-assessment outside the lab. Simulation-based evaluations, including virtual reality (VR) and augmented reality (AR) assessments, further bridge the gap between theoretical knowledge and clinical application by testing students in a self-immersive and risk-free environment.

Combining traditional OSPEs with these digital innovations gives educators a chance to create a more dynamic and effective assessment framework that accommodates different learning styles. This multimodal

approach will not only ensure rigorous evaluation but also foster long-term retention, clinical readiness with adaptive learning strategies which is a key competency for future medical practitioners [29, 30].

The always evolving and never ending discussion regarding the optimal approach for teaching gross anatomy is complex. It mirrors larger shifts in medical education and technological progress. Although becoming scarce for many reasons, the conventional cadaveric dissection continues to be the most engaging and appreciated method for enhancing hands on learning anatomy and emotional courage, required for dealing with patients. Dissection sessions for sure cultivate a strong professional identity with respect for human life and collaborative learning. All the aforementioned attributes are challenging, if not impossible, to reproduce in virtual settings [31].

We must acknowledge that modern challenges such as limited cadaver availability, increased student cohorts and time constraints have encouraged a shift toward complementary or alternative teaching tools. Virtual simulations, AR/VR technologies, and 3D modeling platforms provide flexible, reproducible and scalable learning opportunities. These tools have demonstrated efficacy in enhancing anatomical knowledge, particularly for visual and kinesthetic learners and are now getting increasingly incorporated into unified learning models.

The hybrid model seems to provide the optimal balance between the approaches. Research has repeatedly validated that integrating traditional dissection with digital resources enhances both student satisfaction and academic achievement. McMenamin et al. emphasize that 3D digital anatomy models significantly support early learners in building foundational knowledge before engaging in physical dissection [32]. These integrated models are consistent with humanistic learning theories; the ones that emphasize that learners must build knowledge through active and multisensory involvement.

Nonetheless, the successful implementation of any teaching method depends on more than just the tools themselves. The dedication of the institution, the training of faculty along with the alignment with curriculum objectives

Table 1: Comparison of Gross Anatomy Teaching Modalities

Modality	Strengths	Limitations	Educational Value	References
Cadaveric Dissection	- Tactile/spatial understanding - Fosters empathy and professionalism - Real-life anatomical variation	- Logistical and ethical challenges - Time-consuming - Emotional distress	High – foundational, immersive learning	Winkelmann [17], Jones (2014), Azer and Eizenberg [18]
Prosection	- Efficient - Consistent quality - Suits large groups	- Less hands-on experience - Reduced spatial discovery	Moderate to high – good for introductory learning	Dissabandara et al. [14], McBride and Drake [19]
Virtual Simulations	- Accessible and repeatable - High engagement - Visual clarity	- Lacks tactile feedback - High initial costs	Moderate – best as a supplement to dissection	Nicholson et al. [20], Yamine and Violato [21]
AR/VR Tools	- Immersive and interactive - Ideal for remote/visual learners	- Requires technological literacy - Not fully comprehensive	High – when used with other methods	Tam et al. [6], Pujol et al. [31]
Hybrid Models	- Customizable learning - Balances strengths of all methods	- Requires curriculum planning and resources	Very high – adaptive, multimodal approach	Estai and Bunt [22], Sugand et al. [23]

are essential for optimizing the effectiveness of anatomy education [2,29]. It is essential to take into account the student factors such as prior exposure to the subject basics, personal learning preferences, and emotional reactions to dissection, as some students feel distress during cadaveric dissection, which can affect their learning outcomes if adequate psychological support is not offered timely.

The socio-economic inequalities and geographic constraints hinder fair access to advanced digital resources. While affluent institutions can easily implement state-of-the-art technologies, those with limited resources frequently depend on cost-effective, impactful alternatives like peer teaching, plastinated models and open-source virtual platforms. Consequently, flexibility and inclusiveness should be fundamental to any suggested or planned changes in anatomy education.

Assessment practices also require careful alignment with teaching modalities. Traditional assessments such as identifying the marked spots and OSPEs are well-suited to physical dissection, while virtual quizzes and simulation-based evaluations can better assess skills developed through digital platforms. Innovative assessment models that evaluate critical thinking and clinical application are needed to reflect the holistic competencies expected of future clinicians. Table 1 compares the strengths, limitations of some readily available important teaching modalities.

## CONCLUSIONS

The authors conclude that education of gross anatomy is evolving rather than being entirely replaced. Educators and curriculum designers need to adopt flexible, evidence-based teaching strategies and invest in faculty training, technological infrastructure, and student support systems.

The central challenge lies not in choosing between modalities but in designing integrated curricula that align with institutional capacity, cultural context and student diversity. Digital tools expand access, particularly in resource-limited settings, but equity constraints do persist in various settings. Faculty development and curriculum planning remain essential part of modernizing any teaching method.

By adopting a pluralistic approach to teaching that involves combining traditional methods with contemporary technologies, we the medical educators can address the varied needs of learners, maintain the relevance of their teaching and preserve the integrity of anatomical sciences within modern curricula. An ongoing research into the long-term clinical impacts of different teaching methods will be crucial for shaping future educational strategies and resource allocation.

## Limitations

Restriction to English-language studies may have led to potential language bias. Meta analysis is limited by heterogeneity of study designs. Digital tools vary widely in quality and this can easily complicate comparability. Rapid technological evolution can make some findings quickly becoming outdated.

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## AI use Statement

Artificial intelligence tools were used to assist with language refinement and clarity during the writing process. No other help was used from AI tools for this manuscript. All ideas, analysis, and conclusions are the author’s own and the authors take full responsibility for the content of this review.

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