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# What Counts as Educational Innovation in Clinical Anatomy?

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## ABSTRACT

Clinical anatomy has become a prominent setting for educational innovation because it links anatomical science with diagnostic imaging, procedural practice, surgery, simulation, and patient safety. However, the term innovation is used inconsistently. In PubMed-indexed literature from January 2016 through 28 June 2026, it is frequently applied to augmented, virtual, and mixed reality, 3D printing, virtual dissection tables, ultrasound, artificial intelligence, flipped classrooms, and case-based clinical integration. The central problem is that innovation often refers to novelty of medium rather than to the clinical accountability of learning. This critical narrative review synthesized PubMed-indexed English-language literature published from January 2016 through 28 June 2026 to examine what should count as educational innovation in clinical anatomy and to distinguish meaningful innovation from technological enthusiasm, curricular cosmetic change, or assessment-light experimentation. Included sources addressed human anatomy education with an explicit clinical, diagnostic, imaging, procedural, or health-professional orientation. The literature clusters around seven overlapping domains: collaborative definitions of clinical anatomy, cadaver-imaging integration, 3D printing and pathoanatomical modeling, extended reality, artificial intelligence, ultrasound and living anatomy, and flipped or case-based curricular redesign. Across these areas, innovations are often praised for engagement, visualization, or institutional modernity even when evidence for durable clinical transfer remains limited. Conversely, cadaveric dissection may be genuinely innovative when redesigned around clinical reasoning, imaging correlation, anatomical variation, and procedural safety. Educational innovation in clinical anatomy should count only when it makes anatomical learning more clinically usable, assessable, ethically defensible, and transferable. Technology may support that aim, but it does not define it.

## 1 | Introduction

Clinical anatomy (CA) is often treated as a self-evident phrase: anatomy made relevant to clinical practice. That definition is convenient, but it can also be insufficiently precise. If any lecture that contains a clinical pearl, a radiograph, or a surgeon's anecdote becomes CA, then almost everything and nothing is CA. A recent consensus statement from the American Association of Clinical Anatomists is therefore important because it frames CA not merely as a topic, a teaching venue, or the credential of the instructor, but as the integration of anatomical knowledge with clinical relevance, usually strengthened by collaboration between anatomists and clinicians (Iwanaga et al. 2026). This definition immediately raises the educational question addressed in this article: if CA is integrative by nature, what exactly counts as educational innovation within it?

The question matters because anatomy education has been under pressure for decades: reduced curricular time, larger cohorts, more fragmented basic-science curricula, greater demand

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for early clinical exposure, expanding imaging and procedural technologies, and persistent anxiety among clinicians that students do not retain enough anatomy for safe practice. Studies of stakeholder perceptions have repeatedly shown a mismatch between what students, anatomy educators, and clinicians value or believe is being delivered (Sbayeh et al. 2016; Lunn-Collier et al. 2022). The result is a fertile market for innovation claims. Some are pedagogically serious; others are closer to procurement narratives in which a new device is presumed to produce a new kind of learning.

The last decade of PubMed-indexed literature shows an unmistakable expansion of digital and multimodal anatomy education. Reviews describe the growing use of 3D printing, augmented reality (AR), virtual reality (VR), mixed reality (MR), virtual dissection, mobile applications, artificial intelligence (AI), and other digital systems in anatomy learning (Adnan and Xiao 2023; Santos et al. 2022; Trelease 2016). In CA, these tools are especially compelling because they promise to address a real educational problem: the learner must understand structures not only as labeled objects but as spatial, variable, living, imaged, surgically accessed, and procedurally consequential. A conventional atlas is insufficient for that ambition, but so is a poorly integrated headset or an unvalidated AI tutor.

The controversy is not whether technology belongs in CA. It does. Emerging technologies may offer advantages that conventional approaches cannot easily provide, including repeatable exposure to rare pathoanatomy, interactive manipulation of complex spatial relations, safer rehearsal of procedures, individualized feedback, scalable access to digital models, and integration of imaging or operative viewpoints into early learning. The more precise controversy is whether these advantages are being evaluated against CA outcomes rather than inferred from novelty or engagement alone. AR may be clinically powerful when it overlays donor imaging onto a dissected specimen or supports spatial reasoning around patient-specific anatomy (McBain et al. 2022, 2023). The same AR experience may be pedagogically thin when it produces fascination without transfer. Three-dimensional printing may be transformative when it clarifies complex congenital, craniofacial, cardiac, or surgical anatomy (Al-Badri et al. 2022; Li et al. 2017; Tanner et al. 2020). It may be misleading when a polished model erases tissue texture, anatomical variability, dissection uncertainty, or clinical ambiguity.

This article adopts a critical but constructive position. In CA, educational innovation should not be equated with novelty, digitization, or substitution of cadavers. It should be defined by clinical accountability: Does the intervention help learners interpret images, explain symptoms, anticipate anatomical risk, perform or understand procedures, reason from variation, retain usable knowledge, and communicate anatomy in patient-care contexts? If the answer is no, the intervention may still be attractive, efficient, or engaging, but it should not automatically count as educational innovation in CA.

For the purposes of this review article, clinical transfer is defined as the learner's demonstrable ability to use anatomical knowledge beyond the original teaching representation in a clinical or clinically simulated task. It is broader than short-term recall and narrower than global clinical competence. Clinical reasoning refers to explaining symptoms, signs, risk, or management anatomically; diagnostic interpretation refers to recognizing anatomy and variation in imaging or other clinical representations; and procedural competence refers to safe planning or performance of an intervention. Clinical transfer is the bridge across these outcomes: the capacity to mobilize anatomy flexibly when the representation, context, and consequences differ from those used during initial instruction.

Accordingly, this critical narrative review synthesizes PubMed-indexed literature from January 2016 through 28 June 2026 to answer the question: What counts as educational innovation in CA? The aim is not to rank technologies but to develop a defensible conceptual standard for judging innovation claims in a field where the boundary between meaningful educational redesign and technologically branded novelty is often blurred.

## 2 | Methods

### 2.1 | Review Design and Rationale

This article was conducted as a critical narrative review with a structured literature identification, selection, and synthesis process. The aim was to synthesize how educational innovation is conceptualized, implemented, and evaluated in CA, and to critically distinguish innovations that improve the clinical usability of anatomical knowledge from those that primarily change the instructional medium. A critical narrative design was selected because the review question was conceptual and evaluative rather than narrowly interventional: the objective was not to determine whether a single predefined intervention produced a pooled effect size but to clarify what should count as educational innovation in CA and how such innovation should be judged.

The review therefore included a methodologically diverse body of literature, including randomized and comparative studies, cohort studies, surveys, feasibility studies, qualitative studies, scoping reviews, systematic reviews, meta-analyses, narrative reviews, descriptive reports, and consensus statements. These sources were not treated as equivalent forms of evidence. Instead, they were used according to their methodological contribution: empirical studies informed claims about educational implementation and outcomes; reviews and meta-analyses helped contextualize domains of evidence; qualitative, descriptive, and consensus-based publications informed conceptual interpretation, implementation issues, and professional perspectives.

### 2.2 | Information Source, Time Frame, and Search Limits

The review focused on PubMed-indexed English-language literature published from January 1, 2016 through June 28, 2026. The final search was conducted on June 28, 2026. PubMed was selected as the database of record because the review addressed the intersection of anatomical sciences, medical education, clinical training, biomedical imaging, and health-professional education. To maintain a consistent retrieval standard, articles identified through reference-list checking were retained only

when they were also indexed in PubMed and met the same date, language, and eligibility criteria.

The 2016–2026 timeframe was chosen to capture the contemporary period in which several educational innovations relevant to CA became prominent, including extended reality, virtual dissection, patient-specific three-dimensional modeling, ultrasound-based living anatomy, flipped and blended curricular models, learning analytics, and artificial intelligence-supported education.

### 2.3 | Search Strategy

The search strategy was organized into three concept blocks. The first block identified the disciplinary field: CA, anatomy education, anatomical sciences, gross anatomy, and human anatomy. The second block identified clinical or health-professional orientation: medical education, health-professional education, teaching, curriculum, assessment, clinical relevance, clinical integration, clinical reasoning, imaging, radiology, surgery, simulation, procedural anatomy, living anatomy, and clinical transfer. The third block identified claimed forms of educational innovation: augmented reality, virtual reality, mixed reality, extended reality, virtual dissection, digital anatomy, cadaver-imaging integration, three-dimensional printing, patient-specific modeling, ultrasound, flipped classroom, blended learning, case-based learning, artificial intelligence, machine learning, generative AI, large language models, learning analytics, and assessment reform.

Rather than relying on a single broad search, the strategy used a core conceptual search followed by domain-specific searches. The following PubMed search strings were used, with publication date and English-language filters applied to each search: 1. ("clinical anatomy" OR "anatomy education" OR "anatomical sciences" OR "gross anatomy" OR "human anatomy") AND ("medical education" OR "health-professional education" OR "health professional education" OR teaching OR curriculum OR assessment) AND (innovation OR "educational innovation" OR "clinical relevance" OR "clinical integration" OR "clinical transfer"); 2. ("clinical anatomy" OR "anatomy education" OR "gross anatomy" OR "human anatomy") AND ("augmented reality" OR "virtual reality" OR "mixed reality" OR "extended reality" OR "virtual dissection" OR "digital anatomy"); 3. ("clinical anatomy" OR "anatomy education" OR "gross anatomy" OR "human anatomy") AND ("3D printing" OR "three-dimensional printing" OR "3D printed" OR "patient-specific model" OR "patient-specific modeling" OR "patient-specific modeling"); 4. ("clinical anatomy" OR "anatomy education" OR "gross anatomy" OR "human anatomy" OR "cadaveric dissection" OR "body donor") AND (imaging OR radiology OR radiological OR ultrasound OR "computed tomography" OR CT OR MRI OR "magnetic resonance imaging") AND (education OR teaching OR curriculum OR learning); 5. ("clinical anatomy" OR "anatomy education" OR "gross anatomy" OR "human anatomy") AND (ultrasound OR "point-of-care ultrasound" OR "living anatomy" OR "procedural anatomy" OR "procedural training"); 6. ("clinical anatomy" OR "anatomy education" OR "gross anatomy" OR "human anatomy") AND ("flipped classroom" OR "flipped learning" OR "blended learning" OR "case-based learning" OR "problem-based learning" OR "team-based learning" OR "curricular integration"); 7. ("clinical anatomy" OR "anatomy education" OR "gross anatomy" OR "human anatomy") AND ("artificial intelligence" OR "machine learning" OR "generative AI" OR "large language model" OR "large language models" OR "AI-assisted visualization" OR "learning analytics"); 8. ("clinical anatomy" OR "anatomy education" OR "gross anatomy" OR "human anatomy") AND (assessment OR "applied anatomy" OR "clinical reasoning" OR "spatial ability" OR "spatial understanding" OR retention OR transfer OR "imaging interpretation" OR "procedural confidence").

Reference lists of relevant review articles and conceptually central studies were then inspected to identify additional PubMed-indexed sources that met the eligibility criteria. This step was used to ensure conceptual coverage of the main innovation domains rather than to introduce non-indexed gray literature.

### 2.4 | Eligibility Criteria

Articles were eligible for inclusion when they met all of the following criteria: they addressed human anatomy education; they involved medical students, health-professional students, trainees, clinicians, anatomists, or educators in anatomical sciences; and they included a clear CA orientation. Clinical orientation was interpreted broadly and included diagnostic imaging, radiology, ultrasound, surgery, procedures, pathoanatomy, living anatomy, anatomical variation, clinical reasoning, patient-specific modeling, AI-assisted visualization, assessment of applied anatomical knowledge, or explicit integration of anatomical science with clinical practice.

Articles were also required to contribute either empirical evidence, conceptual clarification, implementation insight, or evaluative discussion relevant to educational innovation in CA. Studies were eligible regardless of methodological design, provided that they addressed an educational question or argument relevant to the review aim.

Articles were excluded when they focused solely on nonhuman anatomy, purely technical device development without an educational aim, noneducational surgical planning, general e-learning without a clear anatomy or CA focus, or commentary that did not contribute substantively to the conceptual or educational question. Non-PubMed-indexed sources and non-English-language publications were excluded to preserve the predefined scope and reproducibility of the search.

### 2.5 | Study Identification and Selection

All records identified through the PubMed searches, PubMed-indexed reference-list checking, and final journal update were exported and screened using the predefined eligibility criteria. The combined search process retrieved 326 candidate records. After removal of 68 duplicates or clearly noneligible records, 258 titles and abstracts were screened.

Screening was conducted in two stages. At the title-and-abstract stage, records were excluded only when they clearly failed to

meet the eligibility criteria. Records that were potentially relevant, conceptually important, or uncertain were retained for full-text assessment. At this stage, 169 records were excluded, leaving 89 full-text articles for detailed assessment.

Full-text assessment examined whether each article addressed human CA education, whether it had a clear educational aim, whether it contributed to the concept or evaluation of innovation, and whether it was relevant to one or more of the review domains. Forty-four full-text articles were excluded because they did not address human CA education, lacked an educational aim, focused on noneducational technical development or surgical planning, or did not contribute conceptually to the review question. Forty-five articles were finally included in the critical narrative synthesis.

The three authors of the present article, all of whom have teaching experience in CA, participated in the selection process. One author performed the database searches and compiled the candidate records. A second author screened titles and abstracts. A third author assessed full texts for eligibility and conceptual relevance. Borderline cases, reasons for exclusion at the full-text level, and the final included set were discussed by all three authors, and final inclusion was determined by consensus.

### 2.6 | Data Charting and Extraction

Each included article was charted using a structured extraction matrix. The following information was recorded: author and year of publication; article type or study design; learner or participant group; educational setting; form of claimed innovation; CA domain; comparator, where applicable; educational outcomes assessed; main findings; methodological limitations; and conceptual contribution to the review question.

For empirical studies, particular attention was given to the type of outcome used to support claims of innovation, including learner satisfaction, perceived usefulness, short-term knowledge gain, spatial understanding, long-term retention, imaging interpretation, diagnostic reasoning, procedural orientation, procedural confidence, applied clinical reasoning, feedback, and feasibility of implementation. For reviews and meta-analyses, extraction focused on the scope of evidence synthesized, the strength and consistency of conclusions, and the relevance of the review to CA education. For descriptive, qualitative, and consensus-based sources, extraction focused on conceptual definitions, implementation barriers, educational rationale, and implications for curriculum design.

### 2.7 | Prioritization and Evidential Weighting

Because this was a critical narrative review rather than a meta-analysis, included sources were not weighted statistically. Instead, they were prioritized according to their relevance to the review question and the strength of the contribution they could make to conceptual synthesis. Greater interpretive weight was given to sources that met one or more of the following criteria: direct relevance to human CA education; explicit discussion of educational innovation; clear clinical orientation; evaluation of outcomes beyond learner satisfaction alone; assessment of applied anatomical knowledge, imaging interpretation, procedural orientation, clinical reasoning, retention, or transfer; methodological influence as a randomized, comparative, systematic, or meta-analytic study; or conceptual importance for defining CA and educational innovation.

Studies reporting learner perceptions or satisfaction alone were retained when they were important for implementation, acceptability, or stakeholder perspectives, but they were interpreted as weaker evidence of educational effectiveness or clinical transfer. Conversely, studies assessing applied learning, retention, imaging interpretation, procedural reasoning, or clinically oriented assessment were given greater weight when evaluating whether an innovation improved the clinical usability of anatomical knowledge. Review articles were used to contextualize bodies of evidence and identify recurring themes, but they were not treated as substitutes for primary evidence when making claims about specific educational outcomes.

No formal risk-of-bias scoring or quantitative quality assessment was performed, because the purpose of the review was critical conceptual synthesis rather than estimation of intervention effectiveness. However, methodological features of the included literature were considered narratively when interpreting the strength of claims. In particular, the review distinguished between evidence of acceptability or feasibility, evidence of short-term learning, and evidence of clinically meaningful transfer.

### 2.8 | Synthesis

The synthesis proceeded in three stages. First, included articles were grouped according to the dominant form of claimed innovation: clinical integration of anatomy teaching, cadaver-imaging integration, three-dimensional printing and patient-specific modeling, augmented/virtual/mixed/extended reality, ultrasound and living anatomy, flipped or blended curricular design, artificial intelligence-supported anatomy education, and assessment reform.

Second, each group was analyzed according to the educational outcomes used to justify innovation. Outcomes were categorized as learner reaction, perceived usefulness, feasibility, knowledge acquisition, spatial understanding, retention, imaging interpretation, procedural confidence, diagnostic interpretation, applied clinical reasoning, feedback quality, assessment validity, or transfer to clinically relevant tasks.

Third, the literature was interpreted through a critical conceptual lens. The central question guiding synthesis was whether the claimed innovation changed the clinical usability, transferability, or assessment of anatomical knowledge, or whether it mainly altered the medium through which anatomy was delivered. This allowed the review to distinguish between technological novelty, curricular redesign, implementation feasibility, and clinically meaningful educational innovation. The final

narrative synthesis was developed through iterative comparison across domains and consensus discussion among the three authors.

The criteria summarized in Table 1 were generated abductively from this process. They were not intended as a formally validated scoring instrument and were not derived from a predefined coding framework. Rather, recurring claims, outcome measures, implementation concerns, and conceptual inconsistencies were compared across domains and refined into a practical interpretive framework. This approach supports the article's central aim: to clarify a contested educational concept and propose criteria for judging whether an intervention represents meaningful innovation in CA.

## 3 | Results

### 3.1 | Clinical Anatomy as a Collaborative Threshold, Not a Decorative Clinical Example

The most basic innovation in CA may be definitional rather than technological. The consensus statement by Iwanaga et al. (2026) is significant because it rejects the idea that CA is defined solely by a clinician's presence or by isolated clinical facts. Instead, CA is produced when anatomical knowledge is deliberately connected to clinical relevance. This distinction is more than semantic. If CA is simply anatomy plus clinical anecdotes, then innovation can be simulated cheaply by adding a few pathologies to old slides. If CA is integrated, collaborative, and clinically accountable, then innovation requires a redesign of objectives, teaching roles, learning activities, and assessments.

Stakeholder research reinforces this point. Sbayeh et al. (2016) found that students, clinicians, and anatomy educators do not necessarily share the same view of the relevance and sufficiency of anatomy education. Lunn-Collier et al. (2022), working in a South African context, similarly reported clinician concern that clinically relevant anatomy is valuable but not always delivered effectively; clinicians were hopeful about technology, but not as an unsupervised replacement for structured pedagogy. These findings expose an incoherence in many innovation claims: the intended end users of anatomy knowledge, as clinicians and future clinicians, often identify problems of integration and relevance, while institutions respond by purchasing tools that may not solve those problems.

A stronger model appears in CA teaching approaches that explicitly connect anatomy with diagnosis and treatment. Zhang et al. (2023) reported improved anatomy performance and student interest after systematic CA teaching, suggesting that clinical integration itself can be an educational intervention. The implication is important for technology-centered narratives: a well-designed clinical sequence may be more innovative than an expensive visual platform if it changes the learner's reasoning. D'Antoni et al. (2019) similarly shifted attention from delivery media to evidence-based learning strategies such as practice testing, distributed practice, and successive relearning. In CA, innovation may therefore mean building durable retrieval and transfer into the course, not simply offering more vivid anatomy.

### 3.2 | Cadaveric Dissection, Virtual Dissection, and Imaging: The Replacement Debate Is the Wrong Debate

Cadaveric dissection is often positioned as the traditional method that innovation will replace. That framing is too crude. Dissection remains educationally powerful because it exposes learners to anatomical variability, tissue planes, three-dimensional relationships, uncertainty, embodiment, death, and professional formation (Ghosh 2017). However, dissection alone does not automatically constitute CA. It can become clinically inert if learners identify structures without connecting them to imaging, symptoms, operative access, or patient safety. Conversely, it can become highly innovative when coupled to body donor imaging, radiological reasoning, procedural orientation, and clinical cases.

Virtual dissection and radiology integration demonstrate this point. Darras et al. (2019) integrated virtual dissection laboratories into a cadaver-based first-year medical anatomy course. The intervention did not simply replace dissection; it placed medical imaging and cadaveric anatomy into dialogue. This is closer to CA than an isolated virtual table demonstration because it asks learners to move between representations of the same body. Similarly, McBain et al. (2023) evaluated AR integration of body donor imaging into anatomical dissection, a model that aligns directly with clinical practice because physicians rarely encounter anatomy as perfectly exposed atlas structures; they encounter it through imaging, limited access, and interpretive uncertainty.

The critical issue is representational translation. A learner who can identify the hepatic portal vein in a cadaver may still fail to recognize it on CT; a learner who can rotate a virtual model may still misunderstand how tissue resists dissection. Educational innovation in CA therefore counts when it helps learners translate among cadaveric, radiological, surgical, and living representations. It does not count merely because a virtual dissection table is visually impressive or because cadaver time has been digitized for convenience. The clinical test is whether the learner becomes better at moving across anatomical representations in ways that matter for diagnosis, procedures, and patient care.

### 3.3 | Three-Dimensional (3D) Printing and Pathoanatomy: When the Artificial Body Becomes Clinically Honest

3D printing has become one of the clearest examples of both promise and inflation in CA education. The promise is real. Three-dimensional printed models can make complex spatial relationships tangible, support surgical rehearsal, enable repeated handling, reduce dependence on scarce cadaveric material, and reproduce patient-specific or pathological anatomy that students may rarely see (Li et al. 2017; Ye et al. 2020, 2023). In CA, this is important because many high-stakes anatomical problems are not generic: craniosynostosis, cardiac anatomy, pterygopalatine fossa access, and retroperitoneal surgery require spatial understanding of particular configurations.

Empirical studies give 3D printing a stronger evidentiary base than many other innovation claims. Al-Badri et al. (2022)

**TABLE 1** | Critical criteria for judging educational innovation in clinical anatomy.

| Claimed innovation | What would make it count as innovation in clinical anatomy | Common incoherence or red flag | Representative literature |
|---|---|---|---|
| Clinical integration/case-based anatomy | Clinical cases determine what anatomy is taught, how it is sequenced, and how learners are assessed. Learners practice explaining symptoms, diagnosis, treatment, risk, and variation anatomically. | Clinical pearls are added to unchanged structure-identification teaching; the assessment still rewards memorization more than clinical reasoning. | Iwanaga et al. (2026), Sbayeh et al. (2016), Zhang et al. (2023), and D'Antoni et al. (2019) |
| Cadaver-imaging integration | Learners translate among donor anatomy, CT/MRI/ultrasound images, sections, operative views, and clinical cases; imaging is not an appendix but part of the anatomical task. | Virtual tables or radiology slides are displayed as spectacle, while learners are not assessed on representational translation. | Darras et al. (2019), McBain et al. (2023), Alexander et al. (2026), and Ghosh (2017) |
| 3D printing and patient-specific models | Models are built from relevant clinical or radiological data, selected for a precise clinical learning problem, and assessed for spatial reasoning, retention, or procedural planning. | The printed object is treated as inherently superior; fidelity, cost, access, tissue limitations, and model exclusions are ignored. | Al-Badri et al. (2022), Li et al. (2017), Tanner et al. (2020), Tan et al. (2022), and Ye et al. (2023) |
| AR, VR, MR, and XR | Immersion supports clinical transfer: image interpretation, spatial orientation, procedure planning, team communication, or anatomy in context. The technology solves a defined learning problem. | Novelty, engagement, and short-term quiz scores are mistaken for durable clinical competence. | McBain et al. (2022), Moro et al. (2017), Moro et al. (2021), Bölek et al. (2021), Salimi et al. (2024), and Williams et al. (2025) |
| Ultrasound and living anatomy | Learners connect surface anatomy, living anatomy, imaging planes, motion, variation, and procedural safety through supervised practice and assessment. | Ultrasound is reduced to image acquisition or demonstration; anatomical reasoning and clinical interpretation are secondary. | Jamniczky et al. (2017), Royer et al. (2017) Smith et al. (2018), Lufler et al. (2022), and Kenny et al. (2022) |

(Continues)

**TABLE 1** | (Continued)

| Claimed innovation | What would make it count as innovation in clinical anatomy | Common incoherence or red flag | Representative literature |
|---|---|---|---|
| Flipped/blended clinical anatomy | Preclass work prepares learners for in-class clinical reasoning, imaging interpretation, procedural orientation, and feedback. Contact time is used for higher-order anatomical tasks. | Lectures are simply moved online; the classroom is not redesigned and assessment remains recall-based. | Ferrer-Torregrosa et al. (2016), D'Antoni et al. (2019), and Zhang et al. (2023) |
| Assessment reform | Innovation is judged by long-term retention, diagnostic reasoning, anatomical explanation, image interpretation, procedural transfer, and safe decision making. | Student satisfaction or perceived modernity is treated as sufficient evidence of innovation. | Al-Badri et al. (2022), Bölek et al. (2021), Williams et al. (2025), Sbayeh et al. (2016), and Lunn-Collier et al. (2022) |
| Artificial intelligence and learning analytics | AI tools are expert-validated, transparent about uncertainty, integrated into cases, imaging, operative views, or assessment, and evaluated for feedback quality, bias, error recognition, and clinical transfer. | AI output is treated as authoritative; hallucinations, anatomical inaccuracies, data provenance, privacy, equity, and outsourcing of learner reasoning are ignored. | Abdellatif et al. (2022), Lazarus et al. (2024), Collins et al. (2024), Joseph et al. (2025), Eldesoqui et al. (2025), Elzayyat et al. (2025), Nakao et al. (2025), Albadawi et al. (2026), and Hamarsheh et al. (2026) |

Abbreviations: AI, artificial intelligence; AR, augmented reality; CT, computed tomography; LLM, large language model; MR, mixed reality; MRI, Magnetic Resonance Imaging; VR, virtual reality; XR, extended reality.

reported that 3D-printed models improved long-term retention in medical education of craniosynostosis pathoanatomy. Tanner et al. (2020) found that a 3D print model of the pterygopalatine fossa enhanced the learning experience, and Lim et al. (2016) compared 3D prints with cadaveric material for learning external cardiac anatomy. Full-color 3D printing and patient-data-based model production further expand the possibility of making anatomy more clinically realistic (Tan et al. 2022; Williams et al. 2020). Henssen et al. (2025) extended this logic by describing an educational program in which students learned to construct 3D and extended reality (XR) models from radiological data, shifting innovation from passive consumption to production and critique of anatomical representations.

Yet 3D printing also illustrates the central incoherence of the field. A printed model may be more clinically honest than a cadaver for a specific pathology, but less clinically honest than a cadaver for tissue variability, texture, and dissection. It may democratize access if shared, durable, and low-cost; it may deepen inequity if it becomes an expensive symbol of modernization. It may support reasoning if embedded in case work; it may become another object to label. The innovation is therefore not the printed object. It is the pedagogical alignment among clinical problem, model fidelity, learner task, assessment, and reflection on what the model excludes.

### 3.4 | Extended Reality: Immersion Is Not the Same as Clinical Transfer

AR, VR, MR, and XR dominate contemporary discussions of anatomy innovation. Their appeal is understandable: they can display anatomy dynamically, support manipulation of 3D structures, reduce barriers to access, and create immersive experiences. Reviews have found that digital anatomy and immersive technologies are increasingly used across health sciences education (Adnan and Xiao 2023; Adnan et al. 2025; Santos et al. 2022). Studies and reviews have also reported that VR and AR can support anatomy learning and engagement (Moro et al. 2017, 2021; Salimi et al. 2024).

However, the CA question is sharper than the general anatomy question. CA does not ask whether learners enjoy immersion or can answer a short posttest after using a headset. It asks whether immersive representations improve their ability to interpret anatomy under clinical constraints. McBain et al. (2022) reviewed AR in clinical anatomical education and emphasized modalities and assessment tools across students, health professional trainees, and surgeons. This literature suggests that AR is most clinically defensible when it overlays anatomy onto a body, model, or specimen and thereby simulates the partial, contextual, and spatially constrained nature of clinical work.

Systematic reviews appropriately temper this optimistic narrative. Moro et al. (2021) reported effects of virtual and augmented reality on test performance, but other syntheses have emphasized variability, methodological limitations, and the influence of learner spatial ability, cognitive load, and implementation context (Bölek et al. 2021; García-Robles et al. 2024; Salimi et al. 2024). A recent CA systematic review focused specifically on postpandemic AR comparisons similarly found that most included learning outcomes were nonsignificant and that risk of bias and limited methodological justification constrained definitive conclusions (Williams et al. 2025). This should not be read as evidence that XR is educationally ineffective. Rather, it indicates that the strength of an innovation claim depends on whether the assessment captures clinically meaningful transfer. Satisfaction, perceived immersion, and novelty are useful but insufficient. In CA, XR counts as innovation when it supports representational translation, clinical decision making, procedural orientation, or anatomical risk anticipation better than feasible alternatives. Otherwise, it is technologically impressive but educationally underdetermined.

### 3.5 | Ultrasound and Living Anatomy: The Most Clinically Accountable Innovation?

Among the innovations reviewed, ultrasound has a distinctive claim to CA because it brings the living body into anatomy education. Unlike cadaveric dissection, ultrasound shows living anatomy in motion; unlike many 3D models, it requires learners to orient the probe, interpret planes, and reconcile surface, sectional, and functional information. It also connects anatomy to point-of-care imaging, physical examination, vascular access, nerve blocks, musculoskeletal assessment, and procedural safety. For that reason, ultrasound may be one of the most clinically accountable innovations in the field.

Several PubMed-indexed studies support this interpretation. Royer et al. (2017) evaluated a hands-on anatomy-centered ultrasound curriculum to supplement graduate gross anatomy. Jamniczky et al. (2017) found that ultrasound-facilitated teaching did not adversely affect gross anatomy learning outcomes despite concerns about cognitive load. Smith et al. (2018) described a paired anatomy teaching assistant and clinician teaching model that improved medical student perceptions of ultrasound, directly exemplifying the collaboration that CA requires. Lufler et al. (2022) evaluated a novel ultrasound curriculum in the anatomy laboratory, and broader systematic work has synthesized ultrasound's role in undergraduate medical anatomy education (Kenny et al. 2022).

Even here, the innovation claim requires caution. Ultrasound can become clinically superficial if learners are trained to acquire images without understanding anatomy, or if ultrasound is inserted as a brief demonstration without integration into assessment. A student who can find the gallbladder on a standardized volunteer has not necessarily learned clinically robust abdominal anatomy. Conversely, a student who uses ultrasound to understand fascial planes, vascular relationships, organ movement, procedural windows, and anatomical variation has crossed a meaningful threshold. Ultrasound counts as educational innovation in CA when it changes how learners connect surface anatomy, living structure, imaging planes, and clinical action.

### 3.6 | Flipped, Blended, and Case-Based Curricula: The Low-Visibility Innovations

Some of the most important innovations in CA are not visually dramatic. Flipped classrooms, blended learning, retrieval

practice, case-based sequencing, and assessment redesign often lack the glamour of XR or 3D printing, but they may be more consequential. Ferrer-Torregrosa et al. (2016) compared AR, video, and notes within a distance learning and flipped classroom anatomy context, illustrating how media choices must be interpreted within instructional design. D'Antoni et al. (2019) argued for evidence-based learning strategies in CA, shifting the field toward durable learning rather than immediate engagement.

The danger is that flipped learning can be reduced to a logistical maneuver: move lectures online, call the course innovative, and leave the clinical tasks unchanged. That is not innovation. In CA, a flipped design becomes innovative when preclass work prepares learners for in-class diagnostic reasoning, imaging interpretation, anatomical explanation of symptoms, procedural planning, and feedback. The innovation is not the video. It is the redistribution of cognitive work so that classroom or laboratory time is used for clinically meaningful reasoning rather than passive reception.

Across all domains, clinical integration also requires assessment reform. If the examination still rewards isolated structure naming, students will rationally prioritize memorization even when the curriculum claims to be clinically integrated. CA assessment should include image interpretation, surface-to-deep reasoning, anatomical explanation of clinical findings, procedural orientation, recognition of variation, AI-output appraisal when AI tools are used, and applied retrieval over time. Without assessment alignment, CA innovation remains rhetorical. The resulting criteria are summarized in Table 1.

### 3.7 | Artificial Intelligence: Adaptive Support, Clinical Visualization, and Accountable Innovation

Artificial intelligence deserves explicit consideration because it is beginning to influence anatomy education through several pathways: generative tutoring, customized anatomy chatbots, automated or semi-automated assessment, AI-assisted anatomical segmentation and visualization, adaptive sequencing, and learning analytics. Reviews and descriptive studies have highlighted the potential of AI to personalize feedback, generate cases or multiple-choice questions, support intelligent tutoring environments, and assist with complex visual anatomy (Abdellatif et al. 2022; Lazarus et al. 2024; Collins et al. 2024; Joseph et al. 2025).

Recent learner-engagement data also indicate that AI adoption in anatomical sciences is not only a technical matter but also an implementation issue: in a CA cross-sectional study of 368 medical students, chatbots were the most frequently used AI tool (73.9%), and use of AI tools or 3D/VR models was associated with more positive attitudes toward AI-integrated anatomical science education (Hamarsheh et al. 2026).

In CA, the strongest AI innovation claim is not that a model can provide fluent anatomical explanations. It is that AI may help learners confront clinically relevant anatomical uncertainty: segmenting operative video or imaging, highlighting anatomical structures or danger zones, generating anatomically grounded clinical cases, supporting individualized remediation, and making assessment feedback more immediate and specific. Studies on LLM-generated CA questions and AI-based surgical anatomy visualization illustrate how AI may connect anatomy with diagnostic, procedural, and operative representations when human expertise remains central to design and validation (Elzayyat et al. 2025; Nakao et al. 2025).

However, AI also intensifies the distinction between novelty and accountable innovation. Generative systems can hallucinate, overstate certainty, reproduce bias, generate anatomically inaccurate images, or encourage learners to outsource reasoning rather than develop it. Evaluations of text-to-image tools in anatomy education show both promise and important limitations (Saluja and Tigga 2024; Eldesoqui et al. 2025). A recent CA comparative qualitative and quantitative evaluation of text-to-image generators found that AI-generated anatomical illustrations can range from medically indistinguishable to biologically impossible, with anatomical accuracy declining as structural complexity increases and expert supervision remaining necessary for educational use (Albadawi et al. 2026). AI should therefore count as educational innovation in CA only when its outputs are anatomist- and clinician-validated, its limitations are taught explicitly, its use is aligned with learning outcomes and assessment, and it improves clinical transfer rather than merely accelerating content production.

Table 1 is intended as a critical interpretive tool, not as a formal grading rubric. The criteria were generated abductively from the review process: recurring claims, outcome measures, implementation concerns, and conceptual inconsistencies were compared across the reviewed domains and then refined by the authors into a practical framework. They therefore represent an author-developed conceptual synthesis grounded in the reviewed literature rather than a formally validated scale. The same technology may count as innovation in one context and as superficial novelty in another, depending on curricular alignment and assessment.

## 4 | Discussion

The literature suggests a simple but demanding answer to the title question: educational innovation in CA counts when it makes anatomy more usable for clinical reasoning, imaging interpretation, procedural orientation, surgical understanding, and patient-safe action. It does not count merely because an intervention is digital, immersive, expensive, recent, or popular. This distinction is essential because CA is not a repository of clinically decorated facts. It is a translation practice that connects structure to diagnosis, treatment, risk, and care.

A first criterion is problem-driven design. Meaningful innovation begins with a CA problem: students cannot interpret sectional images; they forget anatomy before clerkships; they cannot link surface anatomy to deep structures; they struggle with anatomical variation; they cannot visualize surgical corridors; they cannot explain symptoms anatomically; they cannot orient a probe or procedure safely. Once the problem is defined, the educational method can be selected. Sometimes the solution will be AR, VR, 3D printing, or ultrasound. Sometimes it will be a better cadaveric task, a better case, a better assessment, or

spaced retrieval. Technology-first innovation reverses this logic and risks making the tool the curriculum.

A second criterion is representational fit. CA is learned through multiple representations: cadaveric bodies, atlases, diagrams, imaging, endoscopic views, ultrasound planes, 3D printed models, virtual models, operative fields, and living patients. No representation is universally superior. Cadavers show variation and tissue reality but not living motion; ultrasound shows living anatomy but demands skilled interpretation; 3D prints clarify spatial relationships but may sanitize tissue and uncertainty; VR supports manipulation but may detach anatomy from clinical constraints; AR can contextualize anatomy but may overload learners or depend on registration accuracy. Innovation counts when the representation matches the clinical task and when learners are taught the limitations of the representation.

A third criterion is collaborative authorship. CA is not best designed by anatomists alone or clinicians alone. Anatomists protect structural depth, terminology, variation, and conceptual coherence. Clinicians protect relevance, risk, workflow, and patient-care consequences. The most defensible innovations in the literature often involve this kind of collaboration: paired ultrasound teaching, donor imaging integrated into dissection, CA courses built around diagnosis and treatment, and 3D/XR modeling from radiological data. When collaboration is absent, CA can become either clinically shallow anatomy or anatomically shallow clinical demonstration.

A fourth criterion is assessment alignment. The field still overvalues satisfaction and undermeasures clinical transfer as defined in this review. Learners may like VR, printed models, ultrasound sessions, or AI tutors, but satisfaction is not competence. Short-term quizzes are useful but insufficient. For CA, stronger outcomes include retention after weeks or months, interpretation of unfamiliar images, explanation of clinical presentations, identification of anatomical risk in procedures, recognition of variation, performance in simulated clinical tasks, critical appraisal of AI-generated anatomical outputs, and transfer to clerkship or surgical learning. Al-Badri et al. (2022) are notable because long-term retention was evaluated; many other innovation studies do not reach that threshold.

A fifth criterion is ethical and equitable scalability. CA education is global, but the innovation literature often reflects resource-rich assumptions. High-cost XR systems, virtual tables, and advanced 3D printing may widen inequities if they become markers of quality without evidence of superior clinical outcomes. Conversely, reusable 3D models, shared digital repositories, low-cost ultrasound integration, open educational resources, and thoughtfully designed cadaver-imaging tasks may broaden access. Innovation should not be confused with institutional luxury. A resource-constrained anatomy department that builds clinically coherent, assessment-aligned, locally relevant learning may be more innovative than a wealthy department that purchases technology without curricular transformation.

A sixth criterion, made more urgent by AI, is human-centered augmentation. AI tools should be designed to extend expert teaching rather than replace it; they should disclose uncertainty, cite or expose source material where possible, be checked by anatomists and clinicians, and teach learners to recognize erroneous outputs. In CA, AI-based text generation, image generation, image segmentation, and automated assessment are innovative only when they improve feedback, representation, or transfer while preserving professional judgment, privacy, equity, and accountability. Recent CA evidence supports this criterion: text-to-image AI tools require expert validation before educational use (Albadawi et al. 2026), and student engagement data indicate that formal guidance and exposure are needed for AI to function as a practical learning tool rather than an unguided shortcut (Hamarsheh et al. 2026).

The review also challenges a persistent binary: traditional versus innovative. The binary is unnecessarily simplistic. Cadaveric dissection can be conservative when it is reduced to structure naming; it can be innovative when donor imaging, clinical scenarios, surgical approaches, and reflective professional formation are integrated. VR can be innovative when it supports clinical reasoning; it can be conservative when it reproduces atlas labeling in a more expensive form. AI can be innovative when it supports supervised feedback, image interpretation, or clinical transfer; it can be conservative, or even risky, when it generates fluent but unverified anatomical content. Flipped learning can be innovative when it reallocates classroom time to clinical tasks; it can be conservative when it merely relocates lectures. In CA, innovation is not a property of the medium. It is a property of the educational relationship among learner, representation, clinical task, feedback, and assessment.

The central implication is that much of what is called innovation in CA is better described as enhancement, modernization, supplementation, automation, or visualization. These may be valuable, but they are not automatically innovations. A more rigorous vocabulary would distinguish between technological novelty, pedagogical redesign, clinical integration, implementation feasibility, AI-assisted production, and evidence of transfer. Such precision would protect the field from two opposite mistakes: rejecting new tools because they are not cadavers, and accepting new tools because they are new.

For future research, the field needs fewer isolated satisfaction studies and more comparative, longitudinal, and implementation-oriented designs. Studies should compare interventions against strong alternatives, not straw-man traditional methods. They should report cost, faculty workload, access, learner variability, cognitive load, maintenance requirements, and, for AI-enabled interventions, model version, data provenance, prompt or workflow design, expert validation procedures, error analysis, privacy safeguards, and learner oversight. They should evaluate how innovations function across different institutional contexts, including low- and middle-resource settings. They should ask not only whether students learn anatomy but whether they use anatomy better when confronted with clinical ambiguity. That is the standard CA itself demands.

This review should be interpreted as a critical conceptual synthesis rather than as a systematic effectiveness review. Its focus on PubMed-indexed English-language literature and its search window through 28 June 2026 were chosen to maintain a clear biomedical scope, while recognizing that relevant educational innovation may also appear in discipline-specific education

journals, engineering databases, local journals, conference proceedings, institutional reports, or non-English sources. The review did not use duplicate independent screening, formal risk-of-bias scoring, or pooled quantitative synthesis; these choices are consistent with its narrative and conceptual purpose but limit reproducibility and comparability. To improve transparency, the search blocks, inclusion logic, source prioritization, and abductive derivation of the criteria have been specified. CA is also variably indexed, with closely related work sometimes categorized under anatomy education, radiology education, ultrasound education, surgical education, simulation, or AI in medical education; therefore, the synthesis emphasizes conceptual relevance rather than terminology alone. The included literature naturally varies in design and outcome measures, including learner perceptions, feasibility, knowledge tests, retention, AI-output accuracy, implementation findings, and transfer-oriented outcomes, which limits direct comparison but reflects the breadth of a rapidly developing field. Accordingly, this review does not seek to provide a universal scoring instrument; instead, it offers a practical framework for judging innovation claims in relation to curriculum, learner level, resources, faculty expertise, and patient-care context.

## 5 | Conclusion

Educational innovation in CA should be judged by clinical accountability rather than by novelty. An intervention counts as innovative when it improves learners' ability to use anatomy for clinical reasoning, image interpretation, procedural understanding, surgical orientation, patient-specific thinking, and safe decision-making. It should also be assessable, ethically defensible, collaboratively designed, and responsive to the resources and constraints of the educational setting.

The literature from January 2016 through 28 June 2026 shows genuine progress across several domains: donor imaging integrated with dissection, clinically oriented 3D printing, augmented and virtual reality, ultrasound-based living anatomy, AI-assisted tutoring and assessment, anatomical visualization, evidence-based learning strategies, and case-based CA curricula. The most recent work on AI in anatomical science education strengthens this interpretation. AI-generated anatomical images may be useful as supplemental educational material, but their visual realism cannot be assumed to mean anatomical correctness; their value depends on expert review, structured validation, and careful attention to how errors may affect learning. Student engagement with AI tools also appears to be shaped by prior exposure, perceived limitations, and institutional guidance, which means that AI integration should be taught, supervised, and evaluated rather than simply made available.

A recurring incoherence remains: many studies and institutions describe an intervention as innovative because it is technologically novel or engaging, even when transfer to clinical tasks is not demonstrated. The most defensible answer to the question "What counts?" is therefore conditional. Technology counts only when it changes clinical learning. AI counts only when it is validated, transparent, supervised, and oriented toward transfer. Clinical integration counts only when it changes tasks and assessment. Cadaveric work counts when it becomes clinically interpretive. Low-tech redesign counts when it improves durable, transferable anatomical reasoning.

In CA, the future should not be framed as cadavers versus technology, human expertise versus artificial intelligence, or tradition versus innovation. The stronger frame is CA as accountable translation: from structure to image, from image to patient, from patient to procedure, and from procedure back to anatomical understanding. What counts as innovation is whatever makes that translation more accurate, durable, equitable, explainable, and safe.


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### References


Abdellatif, H., M. Al Mushaiqri, H. Albalushi, A. A. A. l-Zaabi, S. Roychoudhury, and S. Das. 2022. "Teaching, Learning and Assessing Anatomy With Artificial Intelligence: The Road to a Better Future." *International Journal of Environmental Research and Public Health* 19, no. 21: 14209. https://doi.org/10.3390/ijerph192114209.

Adnan, S., A. C. Benson, and J. Xiao. 2025. "How Virtual Reality Is Being Adopted in Anatomy Education in Health Sciences and Allied Health: A Systematic Review." *Anatomical Sciences Education* 18, no. 5: 496–525. https://doi.org/10.1002/ase.70027.

Adnan, S., and J. Xiao. 2023. "A Scoping Review on the Trends of Digital Anatomy Education." *Clinical Anatomy* 36, no. 3: 471–491. https://doi.org/10.1002/ca.23995.

Albadawi, E. A., E. M. Embaby, K. I. AlQumaizi, M. A. E. Elsaid, A. F. Dawood, and M. Eldesoqui. 2026. "Anatomical Fidelity in Text-To-Image Generative AI: A Comparative Qualitative and Quantitative Evaluation." *Clinical Anatomy*: 1–12. https://doi.org/10.1002/ca.70177.

Al-Badri, N., S. Touzet-Roumazeille, A. Nuytten, J. Ferri, M.-L. Charkaluk, and R. Nicot. 2022. "Three-Dimensional Printing Models Improve Long-Term Retention in Medical Education of Pathoanatomy: A Randomized Controlled Study." *Clinical Anatomy* 35, no. 5: 609–615. https://doi.org/10.1002/ca.23878.

Alexander, M., M. J. Montalbano, and M. Loukas. 2026. "Learning Anatomy With Radiology: A Systematic Review." *Clinical Anatomy* 39, no. 3: 368–381. https://doi.org/10.1002/ca.70048.

Bölek, K. A., G. De Jong, and D. Henssen. 2021. "The Effectiveness of the Use of Augmented Reality in Anatomy Education: A Systematic Review and Meta-Analysis." *Scientific Reports* 11: 15292. https://doi.org/10.1038/s41598-021-94721-4.

Collins, B. R., E. W. Black, and K. E. Rarey. 2024. "Introducing AnatomyGPT: A Customized Artificial Intelligence Application for Anatomical Sciences Education." *Clinical Anatomy* 37, no. 6: 661–669. https://doi.org/10.1002/ca.24178.

D'Antoni, A. V., E. P. Mtui, M. Loukas, R. S. Tubbs, G. P. Zipp, and J. Dunlosky. 2019. "An Evidence-Based Approach to Learning Clinical Anatomy: A Guide for Medical Students, Educators, and Administrators." *Clinical Anatomy* 32, no. 1: 156–163. https://doi.org/10.1002/ca.23298.

Darras, K. E., R. Spouge, R. Hatala, et al. 2019. "Integrated Virtual and Cadaveric Dissection Laboratories Enhance First Year Medical Students' Anatomy Experience: A Pilot Study." *BMC Medical Education* 19: 366. https://doi.org/10.1186/s12909-019-1806-5.

Eldesoqui, M., E. A. Albadawi, K. I. AlQumaizi, M. N. M. Radwan, H. A. Ebrahim, and M. A. E. Elsaid. 2025. "Assessing the Anatomical Accuracy of AI-Generated Medical Illustrations: A Comparative Study of Text-To-Image Generator Tools in Anatomy Education." *Clinical Anatomy* 38, no. 6: 712–717. https://doi.org/10.1002/ca.70002.

Elzayyat, M., J. N. Mohammad, and S. Zaqout. 2025. "Assessing LLM-Generated vs. Expert-Created Clinical Anatomy MCQs: A Student Perception-Based Comparative Study in Medical Education." *Medical Education Online* 30, no. 1: 2554678. https://doi.org/10.1080/10872981.2025.2554678.

Ferrer-Torregrosa, J., M. Á. Jiménez-Rodríguez, J. Torralba-Estelles, F. Garzón-Farinós, M. Pérez-Bermejo, and N. Fernández-Ehrling. 2016. "Distance Learning ECTS and Flipped Classroom in the Anatomy Learning: Comparative Study of the Use of Augmented Reality, Video and Notes." *BMC Medical Education* 16: 230. https://doi.org/10.1186/s12909-016-0757-3.

García-Robles, P., I. Cortés-Pérez, F. A. Nieto-Escámez, H. García-López, E. Obrero-Gaitán, and M. C. Osuna-Pérez. 2024. "Immersive Virtual Reality and Augmented Reality in Anatomy Education: A Systematic Review and Meta-Analysis." *Anatomical Sciences Education* 17, no. 3: 514–528. https://doi.org/10.1002/ase.2397.

Ghosh, S. K. 2017. "Cadaveric Dissection as an Educational Tool for Anatomical Sciences in the 21st Century." *Anatomical Sciences Education* 10, no. 3: 286–299. https://doi.org/10.1002/ase.1649.

Hamarsheh, D., S. D. Boyajian, M. Lafee, et al. 2026. "AI Educational Engagement Patterns and Their Association With Attitudes Toward AI Integration in Anatomical Science Education: A Cross-Sectional Study." *Clinical Anatomy* 0: 1–9. https://doi.org/10.1002/ca.70163.

Henssen, D., J. Karstens, G. De Jong, et al. 2025. "Implementing 3D Printing and Extended Reality in Anatomy Education: Organization, Evolution, and Assessment of an Innovative Teaching Program in an Undergraduate Medical School in The Netherlands." *Annals of Anatomy – Anatomischer Anzeiger* 257: 152354. https://doi.org/10.1016/j.aanat.2024.152354.

Iwanaga, J., K. Bubb, M. Rajaram-Gilkes, et al. 2026. "What Is Clinical Anatomy? A Consensus Statement From the American Association of Clinical Anatomists." *Clinical Anatomy* 39, no. 1: 72–76. https://doi.org/10.1002/ca.70040.

Jamniczky, H. A., D. Cotton, M. Paget, et al. 2017. "Cognitive Load Imposed by Ultrasound-Facilitated Teaching Does Not Adversely Affect Gross Anatomy Learning Outcomes." *Anatomical Sciences Education* 10, no. 2: 144–151. https://doi.org/10.1002/ase.1642.

Joseph, T. S., S. Gowrie, M. J. Montalbano, et al. 2025. "The Roles of Artificial Intelligence in Teaching Anatomy: A Systematic Review." *Clinical Anatomy* 38, no. 5: 552–567. https://doi.org/10.1002/ca.24272.

Kenny, E. J. G., H. N. Makwana, M. Thankachan, L. Clunie, and A. N. Dueñas. 2022. "The Use of Ultrasound in Undergraduate Medical Anatomy Education: A Systematic Review With Narrative Synthesis." *Medical Science Educator* 32: 1195–1208. https://doi.org/10.1007/s40670-022-01593-y.

Lazarus, M. D., M. Truong, P. Douglas, and N. Selwyn. 2024. "Artificial Intelligence and Clinical Anatomical Education: Promises and Perils." *Anatomical Sciences Education* 17, no. 2: 249–262. https://doi.org/10.1002/ase.2221.

Li, K. H. C., C. Kui, E. K. M. Lee, et al. 2017. "The Role of 3D Printing in Anatomy Education and Surgical Training: A Narrative Review." *MedEdPublish* 6: 92. https://doi.org/10.15694/mep.2017.000092.

Lim, K. H. A., Z. Y. Loo, S. J. Goldie, J. W. Adams, and P. G. McMenamin. 2016. "Use of 3D Printed Models in Medical Education: A Randomized Control Trial Comparing 3D Prints Versus Cadaveric Materials for Learning External Cardiac Anatomy." *Anatomical Sciences Education* 9, no. 3: 213–221. https://doi.org/10.1002/ase.1573.

Lufler, R. S., M. L. Davis, L. M. Afifi, R. F. Willson, and P. E. Croft. 2022. "Bringing Anatomy to Life: Evaluating a Novel Ultrasound Curriculum in the Anatomy Laboratory." *Anatomical Sciences Education* 15, no. 3: 609–619. https://doi.org/10.1002/ase.2148.

Lunn-Collier, R., J. I. Layman-Lemphane, K. J. Baatjes, and J. Correia. 2022. "Clinicians' Opinions on the Clinical Relevance of Anatomy Education at Stellenbosch University." *Anatomical Sciences Education* 15, no. 4: 745–753. https://doi.org/10.1002/ase.2175.

McBain, K., L. Chen, A. Y. J. Lee, J. O'Brien, G. P. J. C. Noël, and N. M. Ventura. 2023. "Evaluating the Integration of Body Donor Imaging Into Anatomical Dissection Using Augmented Reality." *Anatomical Sciences Education* 16, no. 1: 71–86. https://doi.org/10.1002/ase.2157.

McBain, K. A., R. Habib, G. Laggis, A. Quaiattini, N. M. Ventura, and G. P. J. C. Noël. 2022. "Scoping Review: The Use of Augmented Reality in Clinical Anatomical Education and Its Assessment Tools." *Anatomical Sciences Education* 15, no. 4: 765–796. https://doi.org/10.1002/ase.2155.

Moro, C., J. Birt, Z. Stromberga, et al. 2021. "Virtual and Augmented Reality Enhancements to Medical and Science Student Physiology and Anatomy Test Performance: A Systematic Review and Meta-Analysis." *Anatomical Sciences Education* 14, no. 3: 368–376. https://doi.org/10.1002/ase.2049.

Moro, C., Z. Stromberga, A. Raikos, and A. Stirling. 2017. "The Effectiveness of Virtual and Augmented Reality in Health Sciences and Medical Anatomy." *Anatomical Sciences Education* 10, no. 6: 549–559. https://doi.org/10.1002/ase.1696.

Nakao, E., M. Igeta, N. Kobayashi, et al. 2025. "Effectiveness of Artificial Intelligence-Based Visualization for Surgical Anatomy Education: A Cluster Quasirandomized Controlled Trial." *Surgery* 188: 109723. https://doi.org/10.1016/j.surg.2025.109723.

Royer, D. F., R. Kessler, and J. R. Stowell. 2017. "Evaluation of an Innovative Hands-On Anatomy-Centered Ultrasound Curriculum to Supplement Graduate Gross Anatomy Education." *Anatomical Sciences Education* 10, no. 4: 348–362. https://doi.org/10.1002/ase.1670.

Salimi, S., Z. Asgari, A. Mohammadnejad, A. Teimazi, and M. Bakhtiari. 2024. "Efficacy of Virtual Reality and Augmented Reality in Anatomy Education: A Systematic Review and Meta-Analysis." *Anatomical Sciences Education* 17, no. 9: 1668–1685. https://doi.org/10.1002/ase.2501.

Saluja, S., and S. R. Tigga. 2024. "Capabilities and Limitations of ChatGPT in Anatomy Education: An Interaction With ChatGPT." *Cureus* 16, no. 9: e69000. https://doi.org/10.7759/cureus.69000.

Santos, V. A., M. P. Barreira, and K. R. Saad. 2022. "Technological Resources for Teaching and Learning About Human Anatomy in the Medical Course: Systematic Review of Literature." *Anatomical Sciences Education* 15, no. 2: 403–419. https://doi.org/10.1002/ase.2142.

Sbayeh, A., M. A. Qaedi Choo, K. A. Quane, et al. 2016. "Relevance of Anatomy to Medical Education and Clinical Practice: Perspectives of Medical Students, Clinicians, and Educators." *Perspectives on Medical Education* 5, no. 6: 338–346. https://doi.org/10.1007/s40037-016-0310-4.

Smith, J. P., J. L. Kendall, and D. F. Royer. 2018. "Improved Medical Student Perception of Ultrasound Using a Paired Anatomy Teaching Assistant and Clinician Teaching Model." *Anatomical Sciences Education* 11, no. 2: 175–184. https://doi.org/10.1002/ase.1722.

Tan, L., Z. Wang, H. Jiang, et al. 2022. "Full Color 3D Printing of Anatomical Models." *Clinical Anatomy* 35, no. 5: 598–608. https://doi.org/10.1002/ca.23875.

Tanner, J. A., B. Jethwa, J. Jackson, et al. 2020. "A Three-Dimensional Print Model of the Pterygopalatine Fossa Significantly Enhances the Learning Experience." *Anatomical Sciences Education* 13, no. 5: 568–580. https://doi.org/10.1002/ase.1942.

Trelease, R. B. 2016. "From Chalkboard, Slides, and Paper to e-Learning: How Computing Technologies Have Transformed Anatomical Sciences Education." *Anatomical Sciences Education* 9, no. 6: 583–602. https://doi.org/10.1002/ase.1620.

Williams, A., Z. Sun, and M. Vaccarezza. 2025. "Comparison of Augmented Reality With Other Teaching Methods in Learning Anatomy: A Systematic Review." *Clinical Anatomy* 38, no. 2: 168–185. https://doi.org/10.1002/ca.24234.

Williams, M. A., R. W. Smillie, M. Richard, and T. D. A. Cosker. 2020. "Producing 3D Printed High-Fidelity Retroperitoneal Models From In Vivo Patient Data: The Oxford Method." *Journal of Anatomy* 237, no. 6: 1177–1184. https://doi.org/10.1111/joa.13278.

Ye, Z., A. Dun, H. Jiang, et al. 2020. "The Role of 3D Printed Models in the Teaching of Human Anatomy: A Systematic Review and Meta-Analysis." *BMC Medical Education* 20: 335. https://doi.org/10.1186/s12909-020-02242-x.

Ye, Z., H. Jiang, S. Bai, et al. 2023. "Meta-Analyzing the Efficacy of 3D Printed Models in Anatomy Education." *Frontiers in Bioengineering and Biotechnology* 11: 1117555. https://doi.org/10.3389/fbioe.2023.1117555.

Zhang, Y., Z. Ji, P. Zhou, L. Dong, and Y. Chen. 2023. "Clinical Anatomy Teaching: A Promising Strategy for Anatomic Education." *Heliyon* 9, no. 3: e13891. https://doi.org/10.1016/j.heliyon.2023.e13891.