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A DIDACTIC MODEL FOR DEVELOPING PROFESSIONAL COMPETENCIES THROUGH MULTIMODAL LEARNING TECHNOLOGIES IN HUMAN ANATOMY EDUCATION

Narrative literature review and conceptual pedagogical framework

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Abstract: Human anatomy education requires students to integrate spatial representations, anatomical terminology, functional relationships and clinically meaningful interpretation. Conventional lectures and two-dimensional illustrations remain valuable, but a single representational format may not adequately address the range of perceptual and cognitive tasks involved in anatomical learning. This narrative review synthesizes educational principles relevant to multimodal anatomy instruction and proposes a didactic model integrating cadaveric and specimen-based learning, anatomical atlases, cross-sectional imaging, three-dimensional visualizations, short explanatory videos and formative assessment. The model links intended professional competencies to learning activities, modality selection, feedback and evaluation. Rather than assuming that technological novelty produces learning gains, the proposed framework emphasizes constructive alignment, cognitive load management, accessibility, anatomical accuracy and clinically oriented transfer. Practical implementation pathways and a feasible evaluation design are described. The article offers a conceptual basis for curriculum development; no original intervention outcomes or experimental effectiveness estimates are claimed.

Keywords: human anatomy; multimodal learning; didactic model; professional competence; medical education; spatial ability; constructive alignment; digital learning.

Introduction

Anatomical knowledge underpins physical examination, diagnostic imaging, procedural safety and communication across medical specialties. Students must move beyond naming isolated structures toward understanding three-dimensional relations, anatomical variation and the implications of structural damage. This creates a curricular challenge: anatomy is both an information-rich foundational science and an applied discipline whose value becomes visible in clinical reasoning. The contemporary anatomy curriculum therefore needs learning designs that connect factual recall with spatial interpretation and practical decision-making [1, 2].

The increasing availability of virtual dissection tables, interactive three-dimensional models, image repositories and recorded demonstrations has expanded instructional options. Yet adding media does not automatically improve understanding. Students may experience fragmented attention, redundant explanations or excessive visual complexity when resources are assembled without an explicit educational rationale. A didactic model is needed to explain which modality should support which learning outcome, how students should transition between representations and how achievement should be assessed [3, 4].

This article develops a conceptual framework for multimodal anatomy education with particular attention to professional competencies. It treats digital resources as complements to, rather than

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universal replacements for, cadaveric study, prosections, physical models and guided discussion. The intended contribution is an implementable teaching design that instructors can adapt to different resource environments and learner cohorts.

Conceptual Basis of Multimodal Anatomy Education

Multimodal learning, as used here, refers to purposeful coordination of multiple instructional representations and activities, including text, diagrams, physical specimens, imaging, audio explanation and interactive visualizations. The educational goal is not maximum sensory stimulation but better mapping between representations and the target anatomical concept. For example, a schematic drawing can clarify a branching pattern, whereas a computed tomography slice can reveal how the same structure appears in a diagnostic context. Each representation offers a distinct informational advantage and a distinct limitation [3, 5].

Cognitive theory of multimedia learning suggests that meaningful learning depends on selecting relevant information, organizing it into coherent representations and integrating it with prior knowledge. Signaling important structures, segmenting demonstrations and removing decorative content can help learners allocate attention. Cognitive load theory similarly highlights the limited capacity of working memory, especially when novices must simultaneously decode unfamiliar terminology, spatial orientation and clinical relevance [3, 4].

Constructive alignment offers the curricular principle connecting these cognitive considerations to professional outcomes. Learning objectives, classroom tasks and assessments should demand comparable levels of performance. If the desired competence is interpretation of a transverse image, students should repeatedly practice orientation and identification on cross-sectional images; recognition of labels on an isolated diagram alone is insufficient evidence of mastery [6].

Embodied and situated aspects of anatomical learning also matter. Handling specimens, locating palpable landmarks and observing variation can provide experiences that purely screen-based activities cannot fully replicate. At the same time, digital models allow repeated rotation, transparency changes and controlled views of structures that may be difficult to expose physically. Effective design uses the strengths of each modality while explicitly teaching learners to translate between them [1, 2].

Professional Competencies as the Organizing Principle

The first domain is anatomical literacy: accurate use of nomenclature, identification of structures and explanation of relationships among organs, vessels, nerves and fascial planes. Multimodal instruction can develop this competence by pairing concise textual definitions with annotated images and unlabeled retrieval exercises. Learners should progress from recognition toward independent identification across multiple specimens and viewpoints.

The second domain is spatial reasoning. A student may recognize a structure in a familiar atlas plate yet fail to locate it after rotation or on a radiological image. Spatial competence includes mental transformation, appreciation of depth and orientation across axial, sagittal and coronal planes. Activities should deliberately require students to rotate virtual models, predict hidden relationships and verify predictions against cross-sectional images. Such tasks target transfer rather than passive visual exposure [5, 7].

The third domain is clinically contextualized interpretation. Students should explain how anatomical relationships account for symptoms, physical findings and procedural risks. For instance, a case involving wrist numbness can connect peripheral nerve anatomy, the carpal tunnel and examination findings without expecting novice learners to independently establish a diagnosis. The

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instructor must distinguish foundational anatomical explanation from clinical management decisions [1, 2].

The fourth domain concerns collaborative communication and self-regulated learning. Students should be able to justify an anatomical interpretation using appropriate evidence, acknowledge uncertainty and select suitable resources when they encounter gaps in understanding. These habits support later professional learning and reduce reliance on memorized answers that are detached from anatomical reasoning.

Structure of the Proposed Didactic Model

The proposed model contains five connected components: competency specification, diagnostic assessment, sequenced multimodal engagement, guided clinical transfer and feedback-based evaluation. These components form a recurring learning cycle rather than a one-time sequence. Each unit begins by stating observable outcomes, such as identifying the course of a nerve on a specimen and on imaging, explaining its relation to neighboring structures and applying that relationship to a short clinical vignette.

Initial diagnostic assessment identifies prerequisite knowledge and common misconceptions. A short unlabeled diagram task, orientation exercise or low-stakes quiz can reveal whether learners understand anatomical planes and key terms. Instructors can then provide different starting materials: a concise orientation animation for novices, more demanding imaging tasks for advanced students and targeted review for learners who confuse related structures. Differentiation should remain manageable and transparent rather than requiring a complex proprietary platform.

Sequenced engagement proceeds from orientation to structural analysis and then to application. In the orientation phase, learners encounter a simplified overview of the region with explicit learning goals. In structural analysis, they examine an atlas image, physical specimen or prosection and interactive model while comparing landmarks. In application, they identify corresponding structures in radiological images and explain a carefully bounded clinical scenario. Students are asked to articulate what each representation reveals and what it obscures.

Feedback is embedded throughout the cycle. Immediate explanations following retrieval questions help correct misconceptions; instructor-guided discussion addresses ambiguous views and anatomical variation. A final task asks learners to transfer knowledge to an unfamiliar image or case. Results feed back into the next lesson plan, allowing instructors to adjust sequencing, time allocation and modality choice.

Selection and Integration of Instructional Modalities

Cadaveric materials and prosections offer authentic three-dimensional relationships, natural tissue variation and an opportunity to discuss professional respect and ethical practice. Their limitations may include restricted access, preparation requirements and variability in specimen quality. Where available, they should be integrated with clear orientation tasks and supported by diagrams or digital images rather than treated as isolated demonstrations [1, 2].

Anatomical atlases and schematic drawings are especially useful for establishing stable visual landmarks and reducing unnecessary complexity. They can also distort apparent distances or simplify variations. Educators should make these limitations explicit by asking students to compare idealized diagrams with photographs, specimens and imaging. Such comparisons can prevent students from assuming that one illustration represents all normal anatomy.

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Three-dimensional interactive models permit rotation, selective hiding, layered exploration and repeated practice outside scheduled laboratory hours. Their instructional value depends on accurate content, intuitive controls and focused tasks. A virtual model is more useful when students must predict a nerve course before revealing the answer than when they merely rotate structures without a goal. Screen interaction should support anatomical inference rather than substitute for it [5, 7].

Radiological images connect gross anatomy with clinical practice. Beginning with well-chosen labeled slices, learners can progressively identify structures in unlabeled computed tomography, magnetic resonance or ultrasound examples. The instructor should explicitly teach orientation conventions, imaging planes and differences between image appearance and physical tissue. This translation between representations is a central element of the proposed model.

Short video demonstrations can show dissection sequences or explain dynamic spatial relations. However, long narrated presentations may encourage passive viewing. Segmenting content, pausing for prediction questions and providing still frames for annotation can turn video into an active learning resource. Audio narration should complement relevant visuals rather than duplicate extensive on-screen text [3, 4].

Illustrative Teaching Unit: Brachial Plexus and Upper-Limb Neuroanatomy

A teaching unit on the brachial plexus demonstrates how the model can operate in practice. The intended outcomes are to identify roots, trunks, divisions, cords and major terminal branches; explain the spatial relationships of these structures to regional landmarks; and connect selected nerve lesions with expected motor and sensory findings. The unit is not designed to replace a comprehensive clinical neurology or regional anesthesia curriculum.

Before class, students complete a brief diagnostic exercise identifying spinal nerve roots and the anatomical planes of the axilla. They then review a simplified schematic of plexus organization. During class, an instructor uses a prosection or high-quality anatomical photograph to demonstrate the plexus in its regional context. Students compare the specimen with a rotatable three-dimensional representation, identifying differences between schematic arrangement and actual anatomical relationships.

Next, small groups receive an unlabeled illustration and an imaging example. They are asked to locate major branches, explain the limitations of each image and predict the functional consequences of an anatomically defined lesion. The instructor uses questions to redirect attention from memorizing a branching diagram to reasoning about the course and distribution of nerves. Finally, students complete an individual transfer task involving a different viewpoint and a short clinical vignette.

The unit ends with targeted feedback and a brief reflection: which representation clarified the plexus most effectively, where did representations disagree and what additional evidence would resolve uncertainty? The purpose of the reflection is to make students conscious of how they build anatomical knowledge and how to verify their conclusions.

Assessment Strategy and Evidence of Competence

Assessment should measure the same competencies that the instructional design intends to develop. A balanced approach combines low-stakes retrieval questions, specimen-based identification, cross-sectional image interpretation and brief clinical explanation. An objective structured practical examination may include stations requiring identification of anatomical landmarks, explanation of spatial relations and interpretation of clinically relevant images. Clear rubrics improve consistency and make expectations visible to students [6, 8].

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For spatial reasoning, instructors should include unfamiliar orientations rather than only reproducing views used in teaching materials. For anatomical literacy, prompts should distinguish recognition from independent naming and functional explanation. For clinical transfer, students can be asked to justify how a particular anatomical relationship contributes to a symptom or procedural risk, while the scoring rubric focuses on anatomical reasoning rather than unsupported diagnostic certainty.

Formative data can inform instructional decisions, but digital analytics require cautious interpretation. Time spent viewing a model or the number of clicks does not necessarily demonstrate understanding. Stronger indicators include improved accuracy on comparable tasks, the ability to explain errors and successful transfer to new images. Where feasible, assessments should combine performance scores with qualitative observations and learner feedback.

Implementation Conditions and Faculty Development

Institutional readiness is a practical determinant of success. Before introducing new technologies, departments should review access to devices, internet reliability, licensing costs, technical support and availability of anatomically validated materials. Low-resource settings can implement the core principles with printed atlases, projected imaging, shared physical models and short instructor-made videos. The educational design should not depend on expensive equipment when simpler tools meet the same learning objective.

Faculty development is essential because multimodal teaching requires more than technical proficiency. Instructors need to select representations, anticipate misconceptions, manage cognitive load and construct aligned assessments. Collaborative lesson planning among anatomists, radiologists and clinicians can improve the relevance and accuracy of learning tasks. Small pilots followed by revision are preferable to wholesale curriculum replacement without evaluation.

Accessibility should be planned from the outset. Visual resources may require readable labels, sufficient contrast, text alternatives and navigable controls; videos benefit from captions and transcripts. Learners who experience motion discomfort with immersive systems should have equivalent alternatives. Ethical use of cadaveric images, licensed media and student performance data requires explicit institutional safeguards.

Proposed Research Design for Empirical Validation

The conceptual model can be evaluated in a prospective educational study. A feasible design would compare a multimodal, competency-aligned anatomy unit with an established teaching approach, ideally using comparable cohorts and identical learning objectives. Baseline anatomy knowledge and relevant spatial ability should be measured before instruction. Outcomes could include immediate knowledge tests, delayed retention, unfamiliar-image interpretation, structured practical examination scores and learner-reported cognitive load.

If random allocation is not feasible, investigators should document baseline differences and avoid causal claims that exceed the design. Teachers, contact hours, assessment difficulty and access to study materials are potential confounders. Assessment rubrics should be specified in advance, and scoring of performance tasks should be blinded where practical. Qualitative interviews or focus groups could explore how students use different representations and where confusion persists.

The most informative question is not whether a new technology produces higher satisfaction ratings, but whether the integrated instructional sequence improves demonstrable competence and transfer. Cost, feasibility and equity should be evaluated alongside learning outcomes. This article

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proposes such a study but does not report participant recruitment, collected data, statistical analyses or measured effectiveness.

Discussion

The principal contribution of the proposed model is its competency-first logic. Multimodal learning is frequently described in terms of tools: virtual anatomy, video, atlas or simulation. The present framework instead begins with what a future clinician must be able to do and selects complementary representations to support that performance. This orientation is consistent with constructive alignment and avoids technology-centered curriculum design [6].

A second contribution is the emphasis on representational translation. Anatomy learners regularly move between physical structures, stylized diagrams and radiological images, yet these transitions are often assumed rather than explicitly taught. Comparing representations can expose differences in scale, viewpoint, tissue appearance and anatomical variation. Such activities may be especially important for learners who have difficulty forming stable three-dimensional mental models [5, 7].

The model also addresses a central tension in multimedia instruction. Multiple modalities can clarify different aspects of a concept, but simultaneous exposure can overwhelm novice learners. Carefully staged sequencing, short explanations and frequent retrieval tasks may reduce avoidable cognitive demands. The precise balance will vary by learner preparation and the anatomical region under study [3, 4].

There are important limitations. This paper is a narrative and conceptual synthesis rather than a systematic review or a report of a controlled educational intervention. The cited literature supports broad educational principles and identifies relevant anatomy-teaching practices, but it does not establish that this specific five-component model has been experimentally validated. Claims of superiority require direct comparative evidence, preferably including delayed and transfer outcomes.

Conclusion

A competency-oriented multimodal didactic model offers a coherent way to integrate traditional anatomical teaching with digital resources. Its essential elements are explicit outcomes, diagnostic assessment, staged comparison of representations, clinically bounded application and aligned formative and summative assessment. The approach treats atlases, specimens, three-dimensional models, videos and radiological images as complementary tools with different pedagogical functions.

For medical universities, the practical priority is to develop small, well-aligned teaching units and evaluate whether students can apply anatomical knowledge across unfamiliar representations and clinically relevant situations. Future research should test effectiveness, long-term retention, faculty workload and equitable access. Until such evidence is available, the model should be regarded as a structured educational proposal rather than a proven intervention.

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