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Case-based online anatomy education: cross-cultural insights from medical students in Türkiye and the United States

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Abstract

Objectives: Anatomy remains a cornerstone of medical education, and emerging technologies are increasingly employed to enhance students' understanding of complex spatial relationships. This study developed and implemented a case-based anatomy online module utilizing Magnetic Resonance Images (MRIs) of body donors and three-dimensional (3D) models to foster student engagement and promote hypothesis-driven learning.

Methods: Students from the USA (n=40) and Türkiye (n=16) participated in virtual classrooms using distance education tools. Each case-based module included: Subject, Medical History, and Physical Exam, followed by Radiology and Pathology reports. Students generated diagnostic hypotheses during the virtual session, discussed findings in small groups, and accessed 3D segmented, photogrammetric, illustrative anatomical models and web-based MRIs.

Results: Analysis of the results revealed significant differences in student responses between the JABSOM and Türkiye cohorts regarding the online learning modules. The Türkiye cohort consistently rated the modules more favorably across several key areas.

Conclusion: Despite the differences, both cohorts expressed overall satisfaction with this online learning approach, indicating that the method was well-received across cultural and institutional contexts. This pilot study demonstrates the feasibility and effectiveness of integrating MRIs and 3D models into case-based anatomy instruction across international cohorts. The workflow offers a replicable model for future anatomy education, bridging traditional teaching methods with cutting-edge teaching tools.

Keywords: anatomy; case-based learning; distance learning; medical education

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Introduction

Over several decades, and notably throughout the COVID-19 pandemic, medical education delivery paradigms have evolved, making e-learning an indispensable component for sustained instruction.[1,2] However, a critical distinction must be drawn between the "emergency remote teaching" necessitated by the pandemic and the deliberate, high-quality digital pedagogy required for the post-pandemic era. In a cross-sectional study involving 3,286 medical students from 12 countries, participants noted that while the rapid transition offered flexibility (84%), it simultaneously introduced significant pedagogical gaps, particularly regarding motivation and the depth of interaction.[3] As medical schools transition from crisis management to permanent hybrid curricula, a "new normal" is emerging that demands 40% or more online instruction. The challenge, therefore, is no longer simply establishing access to digital platforms, but rather developing standardized, pedagogically sound resources that can replicate the complexity of traditional methods while accommodating diverse, cross-cultural learning environments.[3]

This need for high-quality digital surrogates is particularly acute in case-based learning (CBL). CBL is a well-established educational approach that fosters active engagement, critical thinking, and clinical reasoning through the exploration of real-world scenarios.[4] While traditional CBL relies on resource-intensive, face-to-face small groups, the post-pandemic educational landscape requires scalable solutions. The emergence of online case-based learning (eCBL) offers a response to this need, effectively leveraging the shift toward remote education highlighted by the pandemic.[2,5,6] Research indicates that eCBL can match or surpass traditional formats in terms of enjoyment and learning outcomes if designed properly.[5] However, the rapid digitization of these resources often lacks integration with advanced visual tools, limiting their effectiveness in spatially complex subjects like anatomy.

Radiologic imaging has become an indispensable component of contemporary anatomy instruction. The ability to interpret imaging findings is fundamental to clinical decision-making, and anatomy laboratories uniquely enable learners to connect three-dimensional (3D) anatomical structures with their two-dimensional radiologic representations.[7] Such integration supports deeper comprehension of cross-sectional anatomy while simultaneously reinforcing gross anatomical concepts through clinically relevant visualization. Additionally, incorporating radiologic images into anatomy education has been shown to enhance student engagement, performance, and assessment outcomes by strengthening the link between basic anatomical sciences and clinical practice.[8–10] Yet, integrating these complex visual datasets into accessible online modules remains a technical and pedagogical hurdle for many institutions.

As online learning becomes increasingly prevalent, a critical imperative is to continually evaluate the quality of online content, ensuring that mere digital access translates into genuinely effective learning experiences for students. Consequently, there is a pressing need to evaluate whether integrated digital tools can successfully replace or augment traditional anatomical instruction across different educational cultures. Building upon these pedagogical insights, this study establishes a multi-departmental workflow for the development and implementation of case-based anatomy modules that integrate MRIs with 3D models, and examines their feasibility and educational effectiveness through pilot testing in student cohorts drawn from different institutional settings and cultural contexts.

Materials and Methods

This study was institutionally reviewed by the John A. Burns School of Medicine (JABSOM) IRB and approved (IRB00891). Utilizing a previously established multi-departmental workflow,[11] sixteen body donors were obtained through the JABSOM Willed Body Program and embalmed for the 2019–20 anatomy curriculum. Following preservation, donors underwent high-resolution imaging at Queen's Medical Center using a Siemens Prisma 3T MRI scanner. Anonymized DICOM data was subsequently processed through an online software for radiologist assessment and the integration of medical history and physical exam findings. To facilitate 3D visualization, corresponding pathology reports guided segmentation using Mimics software, with the resulting models uploaded to Sketchfab for annotation and educational display.

Four cases involving abdominal pathologies were selected and developed to align with learning objectives. Each case was supported by clinical, radiological, and pathological reports, along with detailed anatomical correlations. A representative case is described below to demonstrate the structure and delivery of the case-based modules.

Case 1

A 98-year-old Japanese female with a history of hypertension, four pregnancies, cataract surgery, and appendectomy presents with a chief complaint of right-sided pain. Her pain was progressive for 4 days. She complained of nausea and vomiting, dysuria, urgency, and gross hematuria. Upon physical exam, the patient was febrile. Her abdomen was tense and notable for an abdominal mass in the right upper quadrant upon palpation. Costovertebral angle tenderness was present. The pain was confined to the right upper quadrant anteriorly and posteriorly. No rebound tenderness was noted. Urinalysis revealed red blood cells=15/per-high power field (HPF) (reference range 0 per HPF), white blood cells=8/per-high power field (reference range 0 per HPF). Radiology revealed right hydronephrosis and a distended ureter (**Figure 1a**). A segmented 3D model of the hydronephrotic kidney was available for visualization on SketchFab (**Figure 1b**). Pathology findings revealed hydronephrosis (**Figure 1c**), the enlargement of the renal calyces and pelvis due to obstruction to urinary outflow, may be unilateral or bilateral depending on the site/level of obstruction. Causes of hydronephrosis/obstruction include stones, strictures, fibrosis, external compression, and masses/neoplasms.

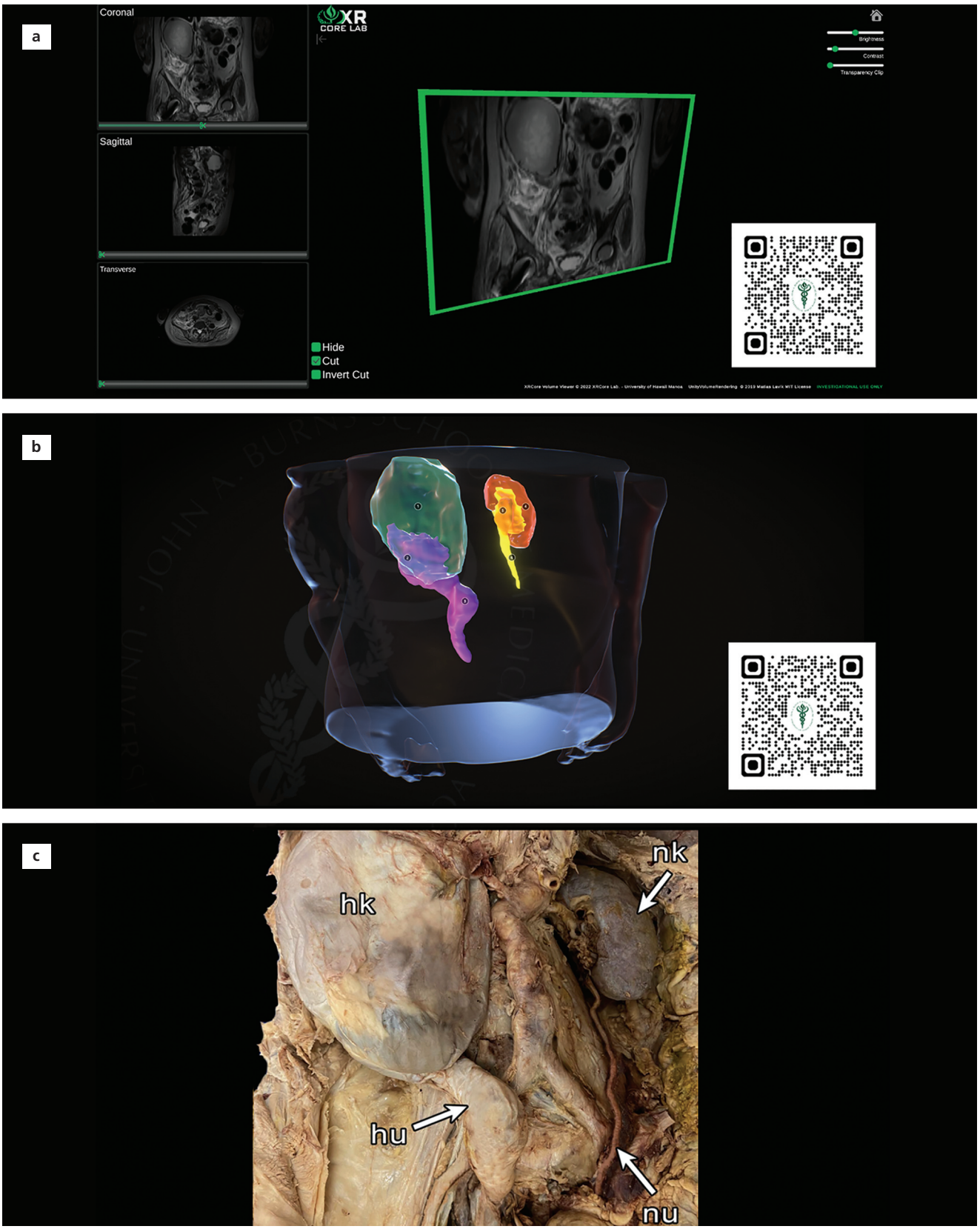


Figure 1. Web-based MRI images of the hydronephrosis case (**a**), corresponding segmented 3D model (**b**), and dissection image (**c**). **hk:** hydronephrotic kidney; **hu:** hydroureter; **nk:** normal kidney; **nu:** normal ureter.

Anatomical correlations

Hydronephrosis can result from a physical blockage in the urinary tract, such as a stone lodged in the ureter. A kidney stone can become lodged in three primary ureteric locations where constrictions exist, including the following: junction of the ureter and the renal pelvis, where the ureter crosses the common iliac artery and pelvic brim, and the point where the ureter enters the urinary bladder. Urinary tract blockages can occur in the bladder or urethra, resulting in vesicoureteral reflux and accumulation of fluid in the kidney and ureter, causing distention. In this case, the hydronephrotic kidney was at least three times the size of the normal, left kidney. The right ureter was greatly distended compared to the left, normal ureter, indicating blockage distal to its termination at the bladder.

Seventy-eight first-year medical students at the JABSOM participated in the virtual class activity as part of the Endocrinology and Gastroenterology curriculum. Twenty medical students (n=20) from various universities in Türkiye were recruited through the Turkish Medical Students' International Committee (Türk Tıp Öğrencileri Birliği - TurkMSIC). These international participants were included based on prior completion of a gastrointestinal anatomy course and English proficiency, allowing for a broader evaluation across different institutions. To accommodate time zone differences, two separate synchronous sessions were held using the same instructor and delivery format. The instructor guided the class through each case, beginning with the subject's demographics, medical history, chief complaint, and physical examination findings. Following the introduction, students were divided into breakout rooms for five minutes to generate differential diagnoses. JABSOM students were placed in their pre-assigned longitudinal dissection groups, while TurkMSIC students were randomized. Upon reconvening, participants submitted their hypotheses via the chat box. The instructor then reviewed the interactive CT scans, radiology reports, and pathology findings, supplementing the discussion with relevant 3D segmented, photogrammetric, and illustrative models.

Following the activity, participants were invited to complete an anonymous post-activity survey to assess their experience and opinions. Response rates were 51% for JABSOM (n=40/78) and 80% for TurkMSIC (n=16/20). The survey instruments were nearly identical for both groups, consisting of eleven shared items: six 5-point Likert scale questions with optional comment fields, two open-ended questions, two dichotomous questions, and one multiple-choice item regarding prior online learning experiences. The JABSOM questionnaire included one additional item assessing interest in zSpace, a virtual reality system available in their gross anatomy laboratory. Likert scale data were compared between the JABSOM and TurkMSIC cohorts using the Mann-Whitney U test. Data were summarized as medians (minimum-maximum) and percentiles. Statistical significance was defined as p-value <0.05.

Results

Analysis revealed significant differences between the cohorts across all Likert-scale items. The TurkMSIC cohort reported significantly higher satisfaction scores compared to JABSOM students in five of the six categories. Specifically, the TurkMSIC cohort found the MR scans more useful for online learning (Q3, $p=0.002$) and anatomical understanding (Q4, $p<0.001$). They also rated the utility of 3D Sketchfab models higher (Q8, $p<0.001$) and expressed a stronger desire for similar future resources (Q10, $p<0.001$) and interactive sessions (Q9, $p<0.001$). In these categories, the TurkMSIC cohort consistently reported a median of 5 (range: 4–5 or 5–5), whereas the JABSOM cohort reported a median of 4 (range: 1–5). Conversely, regarding group dynamics, JABSOM students rated their ability to communicate effectively within breakout groups significantly higher (Median=4.5) than the TurkMSIC cohort (Median=4), as indicated by Q5 ($p=0.037$) (**Table 1**).

Survey results on prior online learning experiences indicated that clear differences emerged between the two cohorts in terms of satisfaction. The TurkMSIC cohort reported markedly higher enthusiasm, with 81.3% of respondents rating their experience as "great," compared with 52.5% of students in the JABSOM cohort. In contrast, comparable proportions of students in both groups characterized online classes as "not useful" (18.8% in the TurkMSIC cohort versus 25% in the JABSOM cohort). Notably, the JABSOM cohort uniquely included a subset of students (12.5%) who had not previously participated in online classes but expressed interest in doing so, whereas all respondents in the TurkMSIC cohort reported prior exposure to online learning. Regarding their use of supplemental online anatomy resources, nearly all participants across both cohorts (n=55/56) reported utilizing various videos and mobile applications. The sole exception was a single participant from the TurkMSIC cohort.

Table 1
Comparison of Likert scale responses between JABSOM and TurkMSIC cohorts. Differences were analyzed using the Mann–Whitney U test.

	JABSOM		TurkMSIC		
Group variable	**Median (min-max)**	**%25-%75 percentiles**	**Median (min-max)**	**%25-%75 percentiles**	**p-value**
Q3. Was viewing the MR scans of the body donors useful as a tool for online learning	4.0 (1.0–5.0)	3.0–5.0	5.0 (4.0–5.0)	4.0–5.0	0.002
Q4. Did viewing the MR scans of the body donors provide an understanding of the relevant anatomy?	4.0 (1.0–5.0)	3.0–5.0	5.0 (4.0–5.0)	5.0–5.0	<0.001
Q5. Were you able to communicate effectively with your breakout group?	4.5 (2.0–5.0)	4.0–5.0	4.0 (1.0–5.0)	3.0–5.0	0.037
Q8. Did the additional 3D models provide a better understanding of the anatomical relationships?	4.0 (1.0–5.0)	3.0–5.0	5.0 (5.0–5.0)	5.0–5.0	<0.001
Q9. Would you like to see more online interactive sessions using the MR scans of body donors?	4.0 (1.0–5.0)	3.0–5.0	5.0 (4.0–5.0)	5.0–5.0	<0.001
Q10. Would you use similar resources in the future?	4.0 (1.0–5.0)	3.0–5.0	5.0 (4.0–5.0)	5.0–5.0	<0.001

Despite this shared reliance on digital tools, the specific resources utilized varied by institution: JABSOM students predominantly cited the use of Acland's Video Atlas of Human Anatomy, whereas the TurkMSIC cohort most frequently utilized Kenhub.

Analysis of open-ended student responses demonstrated strong support for the integration of body donors' MRIs into online anatomy instruction. Across both cohorts, feedback clustered into themes related to perceived educational value, the importance of instructor guidance, enhanced spatial understanding, learner preparedness, and session format (**Table 2**).

Discussion

Anatomy education is increasingly recognized as most effective when delivered through a multimodal approach that combines traditional methods, such as lectures and dissection, with innovative tools like 3D models, imaging, and team-based learning to enhance engagement and clinical relevance.[12] Introducing web-based MRIs and 3D models into anatomy education appears to capture student interest. Both cohorts perceived web-based MRIs and 3D models as valuable tools for learning anatomy, consistent with prior studies showing that interactive 3D visualization enhances spatial understanding and retention of complex anatomical structures.[10,13,14]

The divergent satisfaction scores between the cohorts may be significantly influenced by their differing levels of prior exposure to the instructional tools. For the TurkMSIC cohort, the introduction of MRIs and interactive 3D models represented a novel educational intervention. In contrast, the JABSOM cohort, having had prior access to these resources, likely experienced habituation. As the novelty of the tools faded, these students viewed the technology as a standard curricular expectation rather than an innovation. Consequently, their evaluation likely reflects a more pragmatic assessment of the tool's daily utility and integration into their workflow, free from the "novelty effect" of technological newness. This aligns with the literature that student enthusiasm for e-learning tools tends to diminish as the technology becomes normalized within the curriculum.[15] Another reason for the higher satisfaction reported by the TurkMSIC cohort may reflect the influence of autonomous motivation rather than differences in the educational tools themselves. As self-selected volunteers, these students are likely intrinsically motivated, engaging more deeply with the material and deriving greater enjoyment and perceived value from the learning experience.[16] In contrast, JABSOM students participated as part of a required curriculum, and while they may still find the tools useful, their motivation is partially extrinsic, which can reduce engagement and satisfaction.

Table 2
Thematic analysis of open-ended student comments by cohort.

Theme	Description	Representative Comments
Perceived educational value	A large majority of respondents described the sessions as useful or highly effective learning experiences. Students frequently characterized the modules as engaging, clinically relevant, and superior to traditional online anatomy instruction.	**JABSOM:** "Probably the most useful lecture I have ever had at JABSOM." **TurkMSIC cohort:** "The experience was novel and markedly enhanced learning compared with textbook-based anatomy."
Instructor-guided interpretation	Students emphasized that MR imaging was most effective when accompanied by real-time instructor guidance. Expert explanation during image and prosection review was frequently described as essential for understanding, whereas MR scans viewed independently were perceived as less effective.	**JABSOM:** "They were helpful only when someone was there to point out the features." **TurkMSIC cohort:** "Although initially challenging, the material became clear once the structures were explained."
Spatial and cross-sectional understanding	Many respondents reported improved spatial orientation and understanding of cross-sectional anatomy. The ability to view structures in multiple planes and correlate MR images with prosections and 3D models enhanced comprehension of anatomical relationships.	**JABSOM:** "MR scans are great since they help orient us to different views." **TurkMSIC cohort:** "The scans made it very easy to visualize the pathology."
Learner readiness and radiology background	A subset of students reported difficulty interpreting MR images due to limited prior exposure to radiology or pathology. Responses highlighted the importance of scaffolding, including earlier exposure to normal MRI anatomy or more gradual progression to pathology-based cases.	**JABSOM:** "It was cool to see, but difficult since I'm not familiar with reading MRIs." "It would be helpful if we learned how to look at a normal MRI first." **TurkMSIC cohort:** "Limited familiarity with radiologic terminology made full understanding difficult."
Value of 3D models	Students strongly endorsed the inclusion of interactive 3D models, describing them as enhancing visualization, accessibility, and learner control. These tools were frequently contrasted with static textbook images and traditional atlases.	**JABSOM:** "The MR scans and the 3D models together are very useful." **TurkMSIC cohort:** "3D models provided a clearer understanding compared with two-dimensional atlases."
Group learning and discussion	Many students valued group discussion for collaborative reasoning and peer learning, though some noted challenges related to time constraints and variability in learner levels. Overall, group-based learning was viewed as beneficial for case discussion.	**JABSOM:** "I like doing the cases and discussing them as a group." **TurkMSIC cohort:** "Collaborating as a group accelerates idea development and fosters learning from one another."
Timing and curriculum placement	Feedback indicated differing perceptions of curricular timing. Some students felt the sessions occurred early relative to their pathology knowledge, while others found the approach accessible even at early stages of training.	**JABSOM:** "It was done too early in the course." **TurkMSIC cohort:** "Although I'm not yet a clinical student, this method made the material easy to understand."

Both cohorts reported that the material introduced was difficult to interpret without prior radiology exposure; this intrinsic load likely overwhelmed their cognitive resources. Students reported that the web-based MRIs were highly useful when guided by instructors. Students emphasized that having expert facilitation helped them interpret the images, connect anatomical structures to clinical relevance, and integrate knowledge more effectively. Van Merriënboer and Sweller[17] argue that for novice learners, complex visual tasks must be supported by strong instructional scaffolding to manage this load. This framework explains our finding that students found the MR scans "helpful only when someone was there to point out features".

Finally, this study demonstrates the feasibility and scalability of exporting high-fidelity anatomical resources across institutional and geographic boundaries. Traditionally, high-quality anatomy education has been constrained by physical resources, such as the availability of body donors, 3D segmented and photogrammetric models, and MRIs. However, our results indicate that digital assets developed at a hub institution (JABSOM) can be effectively deployed to external cohorts (TurkMSIC) with high learner satisfaction. This aligns with emerging evi-

dence that digitally enhanced and blended approaches to anatomy education can be effective across varied institutional and cultural contexts. Multi-institutional research has shown that students from different countries often prefer online and blended anatomy learning modalities over traditional lecture-only formats, reporting increased flexibility, access to resources, and opportunities for self-regulated learning within technology-rich environments.[18] Digital collaboration may help reduce disparities in educational infrastructure and broaden access to advanced anatomical training.[19] However, the literature also underscores several challenges associated with cross-cultural implementation, including variability in technological infrastructure and unequal levels of institutional support for educational innovation. Although remote learning technologies show considerable promise for expanding access and strengthening spatial understanding, disparities in access to hardware and software continue to pose barriers to equitable adoption. Moreover, while 3D visualization and image-integrated learning approaches have been shown to enhance comprehension, prior studies emphasize that their educational effectiveness depends on well-defined pedagogical frameworks.[20]

Overall, this pilot study supports the use of multimodal, instructor-guided anatomy resources, including 3D models, imaging, and case-based learning, as an effective approach to enhance student engagement and satisfaction. Importantly, the consistent positive perceptions observed across cohorts suggest that this approach is adaptable to diverse educational and cultural contexts when appropriate instructional scaffolding is provided. Future studies should build on this pilot work by incorporating objective assessments of anatomical knowledge and skills to complement student perceptions. Expanding the study to larger and more diverse cohorts would help determine the generalizability of these findings.

Limitations

This study was conducted as a pilot during the COVID-19 pandemic, which required rapid development and remote delivery of educational resources. While this context demonstrates the feasibility and acceptability of web-based anatomy tools under constrained circumstances, it also highlights several potential limitations. First, the relatively small sample size, particularly in the TurkMSIC cohort, may limit the generalizability of the findings. Additionally, the cohorts differed significantly in composition and motivation, as the TurkMSIC group consisted of self-selected volunteers drawn from multiple medical faculties, whereas the JABSOM group participated as part of a mandatory curriculum at a single institution. This multi-institutional background of the Turkish participants may have introduced variability in prior anatomical training and standardization that was not present in the single-institution US cohort. Finally, the study relied exclusively on self-reported perceptions and satisfaction data, without objective measures of anatomical knowledge retention or competency.

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Conflict of Interest

The authors have no conflict of interest to report.

Author Contributions

GA: conceptualization, methodology, formal analysis and investigation, original draft preparation, review and editing; NAN: conceptualization, formal analysis and investigation, original draft preparation; BM: formal analysis and investigation; JT: methodology; CR: methodology; UYL: methodology; SL: supervision. All authors read and approved the final manuscript.

Ethics Approval

This study was institutionally reviewed by the John A. Burns School of Medicine (JABSOM) IRB and approved (IRB00891).

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