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CLINICAL ANATOMY WILEY

Rethinking gross anatomy in a compressed time frame: Clinical symptoms, not case studies, as the basis for introductory instruction

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Abstract

The goal of this observational study was to develop effective approaches to introduce first year medical students to gross anatomy/embryology in a compressed time frame. Pedagogical reorganization of anatomy instruction in the regions of Lower Extremity and Head and Neck was based upon core clinical conditions taught in second-year and USMLE Step 1 board review courses. These conditions were not presented as clinical problems, as many students had limited prior training in medical terminology, but focused upon clinical symptoms, allowing for direct correlation of structure and function. Instruction stressed vocabulary acquisition and was extended to prepare for laboratory dissections. Overall methodology was multimodal, including "flipped" and traditional lectures, study of prosections/radiographs and small group laboratory review sessions. Content was significantly reduced: knowledge of muscle actions and innervations was required, not muscle origins and insertions. Performance was evaluated by criterion-based written examinations that included a set of questions (34) asked repetitively over an 8 year period (n = 606 students) and by regional practical exams. Mean scores in all areas were sustained or numerically improved, despite the compression of instruction duration. Analysis showed no significant differences based upon question format or instructional modality. Despite the high performance levels, students needing assistance in learning could be identified by score distributions. A survey of students indicated that these changes effectively decreased stress and facilitated review for the USMLE Step 1 Board examination. These results suggest that training in gross anatomy can be modified to a compressed duration by instruction in the context of clinical symptomatology.

KEYWORDS
curriculum, dissection, learning, medical education, vocabulary

1 | INTRODUCTION

Recent reforms in curricula in many medical schools have led to a compression and reduction of the duration of instruction in gross anatomy (AAMC-HHMI, 2009; Halliday, O'Donoghue, Klump, & Thompson, 2015; Hołda et al., 2019; McBride & Drake, 2018; Papa & Vaccarezza, 2013; Sbayeh et al., 2016). A number of schools have adopted integrated systems-based courses that reduce the duration of study of basic science in many disciplines, including anatomy (Klement, Paulsen, & Wineski, 2011; Schwartz, Ajjarapu, Stamy, & Schwinn, 2018; Sugand, Abrahams, & Khurana, 2010; White et al., 2014). Medical schools have also substantially decreased or eliminated traditional lectures, including anatomy (Kamei, Cook, Puthucheary, & Starmer, 2012; Kerby, Shukur, & Shalhoub, 2011; Mazur, 2009; Prober & Heath, 2012; Vasan, DeFouw, & Compton, 2011). Instruction has been replaced by "flipped" lectures and methods such as problem-based instruction, team-based and independent learning that can engender "active" learning (Koles, Stolfi, Borges, Nelson, & Paremelee, 2010; Morton & Colbert-Getz, 2017; Neville, 2009). These methods are "cost effective" and do not require faculty extensively trained in gross anatomy (Vasan et al., 2011; Yammine, 2014). Most of these changes have resulted in reduced time allotted to anatomy instruction (Drake, 2014; Drake, McBride, Lachman, & Pawlina, 2009; McBride & Drake, 2018; Rizzolo et al., 2010).

There have been few specific assessments of the effects of these curricular changes on knowledge of gross anatomy and published studies have reached diverse conclusions (Clunie, Morris, Joynes, & Pickering, 2018; Hołda et al., 2019). Student knowledge of anatomy as a whole has been reported as somewhat higher (Findlater, Kristmundsdottir, Parson, & Gillingwater, 2012), equivalent (Bergman, Prince, Drukker, van der Vleuten, & Scherpbier, 2008) or substantially lower (Hinduja, Samuel, & Mitchell, 2005; Hołda et al., 2019; Papa & Vaccarezza, 2013) in integrated/problem based curricula compared to traditional anatomy instruction. Understanding of surface anatomy (McKeown et al., 2003) and confidence in knowledge of anatomy (Farey et al., 2018) have also been reported as low following training in systems-based curricula. Comparison of scores on United States Medical Licensing Examination (USMLE) Step 1 and Step 2 examinations showed no significant differences between students trained in traditional or integrated anatomy courses (Cuddy, Swanson, Drake, & Pawlina, 2013), but those examinations provide only limited assessment of overall knowledge of anatomy.

Recent changes in medical education have also generated new problems related to student preparedness in gross anatomy and stress (Slavin, Schindler, & Chibnall, 2014). As anticipated in the Carnegie report (a major impetus for curriculum revision), the expansion of class sizes in many medical schools has increased "the diversity of prior knowledge, skills, and abilities that students bring with them to medical school" (Irby, Cooke, & O'Brien, 2010). Compression of the duration of instruction in anatomical sciences has been particularly disadvantageous and stressful for students with limited prior training as it requires simultaneous acquisition of the vocabulary and "grammar" of medicine (Bowen & ten Cate, 2017; Wilson-Anstey, Lambert, & Krog, 2019). The increase in student stress has recently been recognized as a major problem, with consequences in rising rates of attrition, alcohol dependency and even suicide among medical students (Dyrbye, Lipscomb, & Thibault, 2019; Dyrbye, Thomas, & Shanafelt, 2005; Hill, Goicochea, & Merlo, 2018; Jackson, Shanafelt, Hasan, Satele, & Dyrbye, 2016; Laitman & Muller, 2019). However, few studies have proposed specific methods for modifying medical curricula to decrease student stress.

The adverse effect on student well-being was also cited as a major impetus in the recent change in the USMLE Step 1 examination from numerical to pass/fail scoring (Committee to Evaluate the USMLE Program, 2020; Humphrey & Woodruff, 2020). Originally intended to inform a binary decision on licensure, the exam has, instead, been extensively utilized in ranking students for residency programs (Chaudhry, Katsufrakis, & Tallia, 2020; McGaghie, Cohen, & Wayne, 2011). A number of studies have found that this inadvertently led to the development of a self-directed, "parallel" curriculum, in which students focused, through third-party sources, upon clinical topics that were tested on the USMLE Step 1 exam, rather than basic science course material (Burk-Rafel, Santen, & Purkiss, 2017; Kumar et al., 2015).

In confronting these problems, many schools have adopted new approaches for establishing a strong basis of knowledge of anatomy within a clinical context (Bains & Kaliski, 2020; Brooks, Woodley, Jackson, & Hoesley, 2015; Willey, Lim, & Kwiatkowski, 2018). A number of studies have demonstrated the effectiveness of use of multimodal pedagogies (Estai & Bunt, 2016; Johnson, Charchanti, & Toupis, 2012; Klement, Paulsen, & Wineski, 2017) rather than single instructional methods. Multimodal teaching can increase the efficiency of instruction in students with diverse prior training in anatomy (Houser & Kondrashov, 2018) and may also aid to ameliorate some components of stress derived from compressed curricula (Slavin et al., 2014).

Similar changes in the duration of gross anatomy instruction have occurred at the Joan C. Edwards School of Medicine. This observational paper describes pedagogical changes that were developed in preparation for a compression of instruction duration in a new, fully integrated curriculum. A goal of these changes was to integrate content in Anatomy in the Pedagogy in the areas of Head and Neck and Lower Extremity based upon understanding the symptoms of core clinical conditions rather than full analysis of clinical problems, as many students lacked the background for meaningful diagnostic analysis (Al-Jamal, 2018; Bowen & ten Cate, 2017). These changes also sought to integrate the structure and format of the self-directed "parallel" curriculum into formal training in anatomy and clinical science (Committee to Evaluate the USMLE Program, 2020).

The major question (hypothesis) of this study was: can pedagogical changes maintain and consolidate learning in a compressed time frame, while decreasing student stress? In the following, data are reviewed that support this hypothesis. Furthermore, this method provided the context for instruction in anatomy further in the curriculum, could aid students in preparation for board examinations and permit identification of students needing assistance in learning (Gullo, McCarthy, Shapiro, & Miller, 2015; Zill, 2019).

2 | METHODS

Gross Anatomy Instruction and Evaluation—Gross anatomy has been consistently taught by body region at the Joan C. Edwards School of Medicine and evaluated by in-house (custom) written multiple-choice and regional laboratory practical examinations. Examinations were given at the end of study (or midpoint and end for Head and Neck) of each body region. Student scores and point biserial values of questions were obtained from ExamSoft records for the years 2014–2019 or from a website maintained by our school (OME Question Bank) for 2010–2013. Data on student performance on earlier written examinations (2005–2009) were derived from departmental grading reports and the accuracy of the data has been confirmed through records kept by other course faculty. These records were assembled into a long-term database on performance in a spreadsheet (Excel) file and mean percentage scores and standard deviations were calculated. Mann–Whitney-Wilcoxon and Paired *t* tests were used to evaluate the significance of differences in performance using SPSS (v26 IBM) and SigmaStat software (Jandel Scientific). Data for figures were plotted as histograms and scatter plots in SigmaPlot (Jandel Scientific).

As written examinations after 2012 also include questions in other courses that were taught simultaneously, more specific evaluation of performance in gross anatomy was obtained through a database of select repeat questions (Joncas, St-Onge, Bourque, & Farand, 2018). These questions (34) were multiple-choice in format and were asked on examinations in the regions of Lower Extremity and Head and Neck in either identical form or with minor modifications throughout the period of 2012–2019. No consistent changes in performance were observed after the minor modifications. Repeat questions were considered to be Clinical Vignette in format if they referred to the symptoms of a specific patient or Basic Science if they focused upon knowledge of anatomy without directly referring to a clinical case. Student scores on regional practical examinations were assembled from course grading reports. Practical examinations were taken in groups in the gross anatomy laboratory (2005–2019). Tests were timed and students moved through stations with questions on dissections or prosections. Answers were hand-written, fill-in-the-blank format and were graded by the principal instructor in each region.

Survey of Students on Effectiveness of Curricular Revision—A survey was sent by email immediately after completion of instruction to the class in 2019–2020. Students were asked to rate numerically (Likert Scale format: 5 strongly agree, 1 strongly disagree) statements on (a) the effectiveness of the format of Clinical presentation of anatomy, (b) whether the format aided in preparation for the USMLE Step 1 board examination, (c) the effects of the Clinical/Anatomical format on stress in learning. Replies to the survey questions were kept anonymous to faculty as they were returned to the class president (Luke Hamm, MUSOM Class of 2022) who tabulated the results and removed any individual identifiers. The response rate to the survey was 51.5% (41/80 students responding).

3 | RESULTS

3.1 | Adapting to changes in curricula and decreased duration of instruction in gross anatomy

In the years prior to 2005, gross anatomy instruction at the Joan C. Edwards School of Medicine was initiated at the start of the first year of medical school. The course was first given over the entire year and then limited to the first semester, concurrent with courses in biochemistry, cell biology and introduction to clinical medicine. The course consisted of lectures (7–10 per week) and laboratory sessions (2–3 per week, each 3–4 hr in duration, 6–8 students per cadaver) with full cadaver dissection, as well as study of prosections and images. After a series of curricular revisions, integration of first year basic sciences was initiated in 2012 and anatomy was taught and tested in short (typically 2–3 week) blocks with other disciplines. The number of disciplines taught simultaneously increased (beginning in 2014–2015, for example, Neuroanatomy/Neuroscience was taught in blocks concurrent with Head and Neck gross anatomy). The number of lectures and laboratory sessions in anatomy initially remained the same but decreased (∼20%) in the last academic year (2019–2020) of this study.

During the period of 2010–2019, the duration of anatomy instruction has been substantially compressed: the histograms in Figure 1 plot the duration of instruction (number of days from start to completion of instruction) for Lower Extremity (left) and Head and Neck for years 2010 and 2017–2019. There has been a 65.2% decrease in duration for the region of Lower Extremity and 41.0% for Head and Neck instruction.

3.2 | Pedagogy based on clinical symptoms

Pedagogical changes were made with the goal of modifying the emphasis and content to provide a basic foundation of knowledge in anatomy within the compressed duration while preparing students for the USMLE Step 1 Board Exam. Specific clinical conditions were identified for each anatomical region (Figure 2) that were a subset of those taught in second-year courses (diseases and therapeutics) at the Joan C. Edwards School of Medicine. Many of these conditions were also found in sources (board review books, websites) used for study for the USMLE Step 1 examination. The conditions were selected based upon their association (cause, symptom) with specific anatomical changes and many had previously been presented as clinical correlates of anatomy.

Anatomy teaching was reorganized as logical extensions of the symptoms of the clinical syndromes. Clinical/anatomical charts (Figure 3a) were introduced in 2014 and initially used as review material. However, these charts and clinical conditions were progressively incorporated as primary teaching material in the period of 2015–2019. For example, circulation of the Lower Extremity was presented and then discussed in the clinical contexts (Figure 2, Left column): understanding of the symptomatology of varicose veins was established by elucidating the anatomical organization of venous drainage (superficial and deep veins, “muscular pump”) and the presence of valves and anastomoses (perforating veins). The specific causes of the pathology (e.g., thrombophlebitis) were not elucidated at that time but discussion was extended to understand the adaptation of anatomy to resist the physical effects of gravity in standing and walking. Other conditions also served as mechanisms for understanding the relationship of structure and function of the circulatory system: treatment of bleeding (laceration) of the femoral artery formed the basis for discussion of the function of arterio-arterial anastomoses in allowing normal compression of arteries associated with joint movements (flexions).

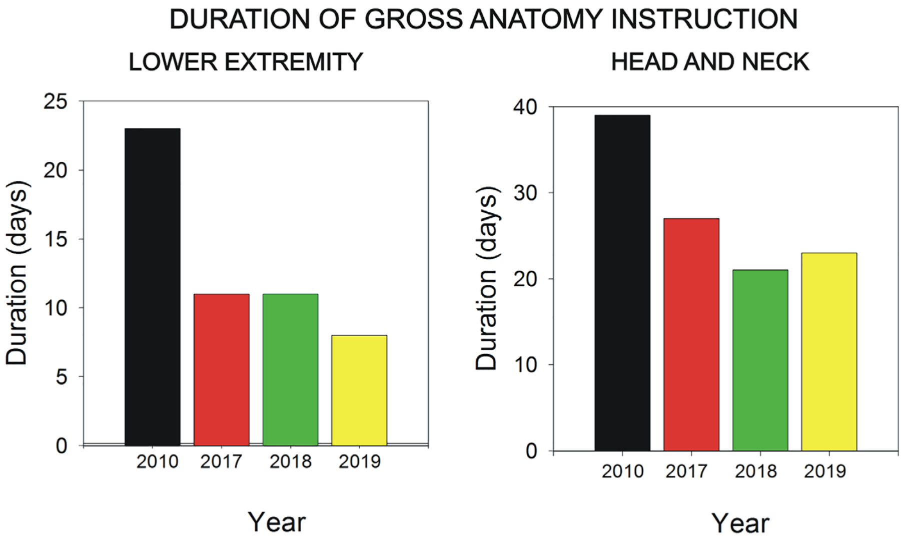

FIGURE 1 Duration of gross anatomy instruction—These plots compare the duration of instruction (number of days from start to completion of instruction) for Lower Extremity (left) and Head and Neck for years 2010 and 2017–2019 and reflect a substantial compression in the duration of study [Color figure can be viewed at wileyonlinelibrary.com]

CORE CLINICAL DISEASES, SYNDROMES

Lower Extremity	Head and Neck I Embryology	Head and Neck II + Spine
- Varicose Veins - Femoral Hernia - Hip Pointer - Pulled Groin - Weaver's Bottom (Ischial bursitis) - Hamstring Pull - Gluteal Gait - Piriformis Syndrome - Wound to Femoral Artery: Collateral circulation at hip - Avascular necrosis of head of femur (Fracture femur) - IT Band (Tract) Syndrome - Dislocate Hip - Clergyman's Knee - Housemaid's Knee - Tear Anterior Cruciate Ligament (ACL) - Terrible Triad - Foot drop - Anterior Leg Syndrome - Tarsal Tunnel Syndrome - Intermittent Claudication - Ankle sprain - Pott's Fracture - Fallen Arch (Pes planus) - Genu Valgum/Varus	- Fracture of cribriform plate of ethmoid bone - Rapid loss of vision in one eye - Slow loss of vision in one eye - Abducens nerve palsy - Trochlear nerve palsy - Oculomotor nerve palsy - Horner's Syndrome - Cavernous sinus thrombosis - Epidural Hematoma - Subdural Hematoma - Communicating Hydrocephalus due to decreased CSF reabsorption - Numbness of regions of face - Pain in external auditory meatus following Facial paralysis - Weakness of muscles mastication - Facial paralysis (with effect on VIII) - Facial paralysis (no effect on VIII) - Cleft Lip (cheiloschisis) - Malformation of nasolacrimal duct (dacryostenosis) - First Arch (Treacher Collins) Syndrome - Thyroglossal duct cysts - Abnormal location/Accidental Removal of parathyroid glands - Branchial cleft syndromes	- Loss of function of IX and X - Fracture of cribriform plate of ethmoid bone - Hoarse voice after thyroid surgery - Torticollis - Cleft Palate (palatoschisis) - Paralysis of muscles of tongue - Knife wound to neck - Pyramidal Lobe of Thyroid gland - Retropharyngeal abscess - 'Toothache' from Maxillary sinus infection - Metastasis of Cancer of tongue) - Dysphagia from Food caught in Throat - Dyspnea in Anaphylaxis (Anaphylactic Shock) - Complications of Carotid Endarterectomy - Complications of Tonsillectomy - Headache (Meninges) - Paraplegia after Treatment Aortic Aneurysm (Iatrogenic) - Spread of Cancer to Vertebrae

FIGURE 2 Core clinical diseases syndromes used as a context for anatomy instruction—Instruction in the regions of Lower Extremity and Head and Neck was reorganized based upon a core set of clinical conditions. These conditions have been taught in second-year courses (diseases and therapeutics) and/or studied in USMLE Step 1 board review

The shift to a clinical focus did not limit the extent of anatomy instruction. For example, the symptoms of Horner syndrome formed the basis for discussion of the structure of the autonomic nervous system (Figure 3a). The pathways of sympathetics (divergent two neuron arcs) to the skin allow for synchronous activation of sweat glands in thermoregulation, with the consequence that damage produced dry

(a) **CLINICAL ANATOMY OF HEAD AND NECK**

Clinical	Anatomy	Cause	Sign/Symptom
Fracture of cribriform plate of ethmoid bone	Nasal septum continuous with crista galli of ethmoid bone; Olfactory nerve passes through cribriform plate of ethmoid bone	Blow to nose; fracture produces **continuity between subarachnoid space and nasal cavity**	**Leakage of CSF from nose** ('runny nose'); **Decreased sense of smell** (hyposmia)
Abducens nerve palsy	Abducens nerve innervates only Lateral Rectus muscle (action: abduction of eye)	Damage Abducens nerve VI (causes ex. increased intracranial pressure, Cavernous sinus thrombosis)	**Diplopia and Medial strabismus**
Horner Syndrome	Sympathetics in head innervate smooth muscle part of Levator Palpebrae Superioris; Pupillary Dilator muscle; sweat glands of skin; **Pathway**: pre-ganglionic neurons out cord at T1,2; ascend in chain; post-ganglionics in Sup. Cerv. Ganglion; distributed with arteries (ex. Ophthalmic A.)	Block conduction in Sympathetics to head (tumors, etc)	**Ptosis** (drooping eyelid from smooth muscle part of Levator Palpebrae Superioris); **Constricted pupil** (miosis due to paralyze Dilator pupillae); **Anhydrosis** of forehead (denervate sweat glands)
Subdural Hematoma	**Bridging veins** link Superficial cerebral veins on surface of brain and Superior Sagittal sinus (also other venous sinuses)	**Blow to head; in elderly can occur without distinct event**	**Slow onset** of neurological symptoms, headache (often hours to days) (Note: **hematoma is crescent-shaped** on CT)
Epidural Hematoma	**Middle Meningeal artery** (branch of Maxillary artery that passes through foramen spinosum) supplies bone of calvarium	**Blow to side of head (fracture skull in region of pterion)**	Patient conscious after accident; loses consciousness within hours; coma, death (Note: **hematoma is lens-shaped** on CT)

(b) **PEDAGOGY AND IMAGES**

STUDENT LABORATORY DISSECTION — INDEPENDENT LEARNING

BRAINSTEM IN CRANIAL CAVITY — PROSECTIONS — CT IMAGE SERIES

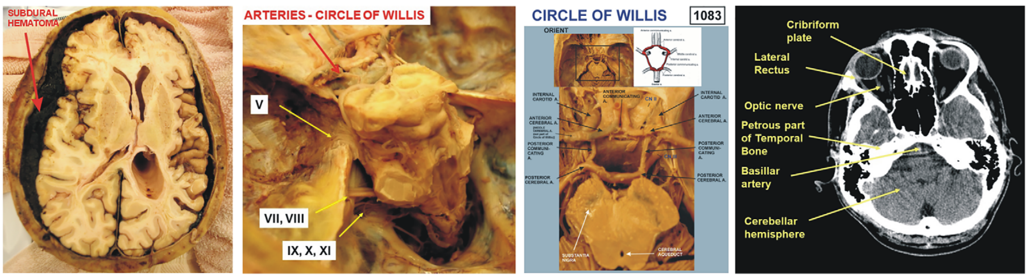

FIGURE 3 Clinical/anatomical format and multimodal pedagogy—(a) Anatomical basis of symptoms of clinical syndromes—Predominant symptoms were identified for each clinical syndrome. The anatomical basis of that symptom was utilized to introduce discussion of the related body structures/systems. The detailed pathology was not discussed but provided a foundation for understanding the relationship between anatomical structure and function. (b) Laboratory dissection, prosections—All students participated in cadaver dissections, augmented by independent study of prosections with photographic and radiological images. Dissections were modified (e.g., brainstem) to maximize cognizance of three-dimensional structure [Color figure can be viewed at wileyonlinelibrary.com]

skin (anhydrosis). The requirements for control through descending pathways from the hypothalamus and activation and distribution through spinal and cranial nerves led to an understanding that Horner syndrome could result from damage at a number of anatomical locations, including cervical lesions (e.g., Pancost tumors) that can produce symptoms in the eye and face (ptosis, miosis).

The format of “flipped” instruction was also introduced in the academic year 2019–2020. Students were given short videos (typically less than 20 min) as an introduction to the anatomy of particular regions prior to lecture/discussion. In class, the content of the videos was discussed within the context of clinical conditions. For example, the basic anatomy of the spinal cord was introduced in video, including discussion of the sensory input and motor output pathways and extended to a description of the anatomy and normal functions reflex pathways. In class, the symptom of hyperreflexia formed the basis for extending learning to an understanding of the need for descending and local modulation of reflexes. Thus, the symptomatology of the clinical condition (spinal cord injury) formed the basis for discussion of structure and function, even when the order was arranged as basic science followed by clinical context.

However, some content was de-emphasized or eliminated to adapt to the time compression. The retention of rote memorization is strongly dependent upon the duration of study (Dempster, 1988). As instruction in Lower Extremity was limited to 6 days in 2019 (Figure 1), rote memorization was decreased and students were required to learn only muscle actions and innervations, not their origins and insertions (although identification of individual muscles on cadavers was still required on practical examinations). Knowledge of some origins/insertions was required when clinically or conceptually relevant: for example, in discussion of the symptoms of Gluteal Gait, the origin of the Gluteus medius muscle (lateral aspect of the ilium) was stressed as that contributed to understanding of the muscle action in shifting support of body load. In Head and Neck, students were no longer required to memorize all the branches of the maxillary artery, only those directly contributing to major clinical conditions (such as the middle [and accessory] meningeal arteries to epidural hematoma). However, instruction did include identification of the major branches of the external and internal carotid arteries which were tested on radiological images.

Most laboratory dissection sessions have been maintained during this period, augmented by a multimodal approach utilizing prosections and radiological images (Figure 3b). Students still performed extensive dissections of the Lower Extremity, with required identification of major structures on practical examinations. In Head and Neck, full dissections of the cranial cavity (preserving the brainstem), orbit, neck, and oral and nasal cavities (head bisection) were performed by students. However, other regions were studied only in prosection (e.g., joints of lower extremity, infratemporal fossa, suboccipital region) as dissection of these structures is more complex and time consuming. Study of prosections was facilitated by distribution of labeled photographic images of specimens although knowledge was tested in practical exams on the original specimens.

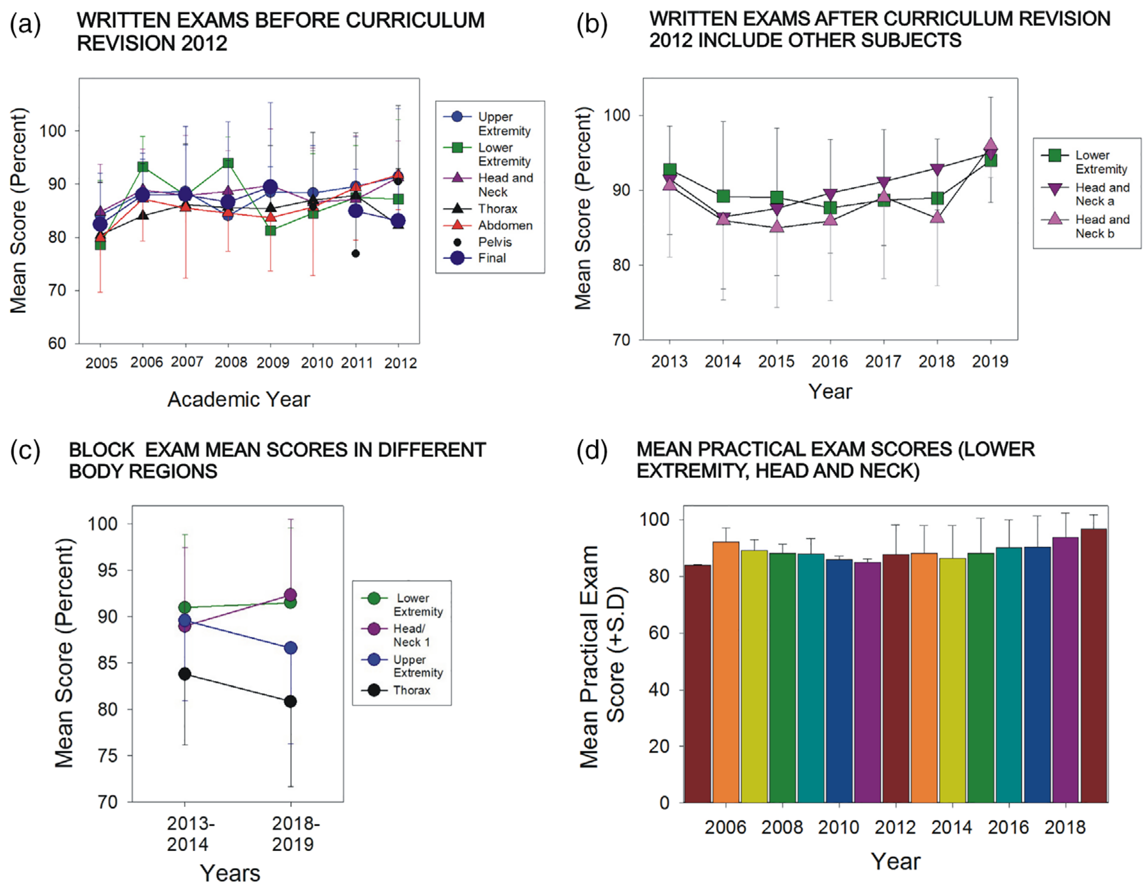

FIGURE 4 Extended database for evaluation of student performance—(a) Data base for long term evaluation. In the period of 2005–2012, examinations in gross anatomy were given at the end of study of each body region and comprehensive final exams were given at the end of study of gross anatomy. Histogram of mean scores (+*SD*) of students (*n* = 592 students) indicate that performance was high and relatively constant. (b) In the period after curriculum revision (2013–2019), students were given block examinations in which gross anatomy was a major component but other courses were tested simultaneously. Student performance on block exams (*n* = 586 students) remained high. (c) Plot comparing block exam scores in different body regions for years 2013–2014 and 2018–2019. Scores in Head and Neck and Lower Extremity remained relatively constant while scores in other body regions (upper extremity, thorax), which did not change pedagogical format, declined numerically. (d) Scores on gross anatomy practical exams (Lower Extremity, Head Neck combined) throughout the period of 2005–2019 (total = 1,178 students) [Color figure can be viewed at wileyonlinelibrary.com]

3.3 | Multiyear data base for evaluating performance

A multiyear data base of student exam scores was used to assess performance although long term comparisons were complicated by the introduction of other courses that were taught and tested simultaneously (gross anatomy was still a major focus). Figure 4a shows mean scores and standard deviations (*n* = 55 exams taken by 592 students) of gross anatomy written examinations (in all body region) and comprehensive final examinations from 2005 to 2011 (before the last curriculum revision). The written examinations specifically tested only knowledge in gross anatomy in specific body regions. Figure 4b shows mean scores on block examinations (for the regions of Lower Extremity and Head and Neck) that included other subjects after curriculum revision. Student performance on those examinations remained high and did not differ from the mean scores in which gross anatomy was specifically tested by body region (*p* = .45, Students *t* test). Figure 4c is a plot of the mean scores on block examinations in Lower Extremity, Head and Neck, in which pedagogy was changed, and in other body regions (Upper Extremity, Thorax), in which teaching format remained constant, for the years 2010 and 2017–19. Comparison of data within this period showed that the mean scores for exams in the years 2013–2016 were Lower Extremity 89.7 ± 2.2 *SD*, Head and Neck 88.7 ± 2.2 *SD*, Upper Extremity 89.3 ± 3.6 *SD*, Thorax 83.0 ± 3.0 *SD* while scores in the period of 2017–2019 were Lower Extremity 90.6 ± 3.0 *SD*, Head and Neck 92.0 ± 0.9 *SD*, Upper Extremity 86.2 ± 2.0, Thorax 78.9 ± 3.4 *SD* (Note: data on the Thorax exam for 2017 was not available). Scores in Thorax and Upper Extremity showed a small decline over this period (although variations in teaching of other disciplines may have occurred) while performance Lower Extremity was unchanged and scores in Head and Neck improved numerically. Figure 4d is a plot of the mean scores on practical examinations in the areas of Lower Extremity and Head and Neck for the years 2005–2019 (*n* = 37 examinations, total = 1,178 students). Mean scores on laboratory exams showed numerical improvement during the period of 2014–2019.

3.4 | Analysis of repeat questions

Specific data were obtained by evaluation of performance on a subset of 34 questions in gross anatomy in the areas of Lower Extremity and

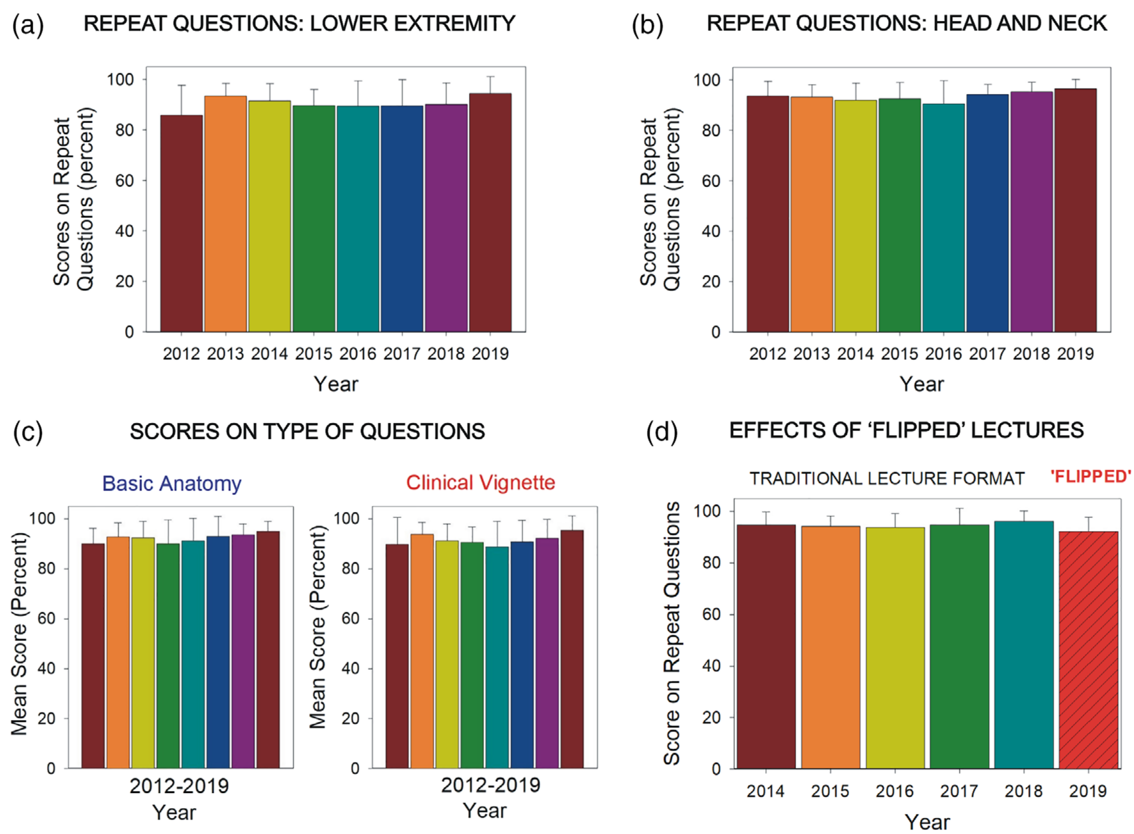

FIGURE 5 Analysis of repeat questions in gross anatomy—(a) Histogram of mean performance on questions in Lower Extremity anatomy (*n* = 17) asked repeatedly (or with minor modification) over an 8 year period (2012–2019; *n* = 643 students), including the curriculum revision in 2013. (b) Similar histograms of performance on questions (*n* = 17) in Head and Neck Anatomy over the same period (*n* = 606 students). (c) Types of repeat questions—This histogram plots mean scores on different types of questions (data from both anatomical body regions). Performance remained high regardless of the question type or body region. (d) Flipped lectures were introduced in 2019 in several areas. This histogram plots student performance on repeat questions (*n* = 6) in areas of spinal cord structure and reflex function for the flipped lectures (2019) and for the same questions in previous years (total *n* = 490 students): performance was statistically unchanged [Color figure can be viewed at wileyonlinelibrary.com]

Head and Neck that were asked repetitively in successive years. The subject and correct answers of all questions remained constant but minor modifications in some years were made the to the text, format or distractor answers. Figure 5a is a plot of the mean scores on 17 questions in Lower Extremity anatomy that were asked repeatedly from 2012 to 2019 (8 examinations taken by *n* = 643 students). Figure 5b is a similar plot for questions in Head and Neck Anatomy (16 examinations taken by 606 students) over the same years. Scores on all repeat questions remained high and numerically increased in the years 2016–2,109. Comparison of pooled data from 2016/2017 and 2018/2019 showed a small, statistically significant increase in performance (Wilcoxon Signed Rank Test, $p \le .01$).

Student performance was also analyzed according to the format of the repeat questions (Basic Science or Clinical Vignette, see Section 2). Figure 5c shows plots of student performance on the types of questions from 2012 to 2019 (same data set as Figure 5a,b). There were no statistically significant differences in the mean scores (Vignette mean 91.5 ± 2.2 *SD*; Basic Science 93.3 ± 1.8 *SD*) or in comparison of individual questions over this period. In addition, changes in scores were calculated for successive years after their introduction to test whether students had prior knowledge of question repetition (Wood, 2009). The mean changes in scores of all 34 questions in the first 2 years was −1.5 ± 6.2 *SD* and only gradually increased as mean scores rose in successive years. Thus, students apparently had no prior knowledge of question repetition.

3.5 | Effects of instructional modality

The effects of “Flipped” lectures were also evaluated by using “repeat” questions on written examinations. Figure 5d is a plot of student performance on questions (*n* = 6) in areas of nervous system anatomy and reflex functions for the flipped lectures (2019) and for the same questions in previous years (2014–2018) in which the material was presented by conventional lectures (total *n* = 490 students): The mean performance was slightly lower for the “flipped” lecture year when compared to conventional lectures (mean flipped 92.2 ± 5.7 *SD*; conventional 94.8 ± 4.9 *SD*) although this difference was not statistically significant. Mean scores on all “flipped” lecture questions were similar to the mean of all other repeat questions (91.8 ± 1.99 *SD*). Thus, student scores showed no correlation with pedagogical format.

3.6 | Quantification of student performance

As student performance was uniformly high, we examined the biserial point values of repeat questions (calculated in ExamSoft or by our school's Office of Medical Education) to assess their effect in detecting students with academic difficulties. The mean point biserial value for repeat questions in the areas of Lower Extremity and Head and Neck given in the years 2012–2019 was (0.287 ± 0.074). Figure 6a is a plot of the mean biserial value (+*SD* averaged over) for each questions versus the mean student score on those questions. The point biserial values showed large variations and regression analysis showed only a weak correlation with the student scores (r^2 = .28).

3.7 | Identifying students needing assistance in learning

Previous studies have indicated that the scores on examinations in the first year of medical school can be used as a measure to identify students needing assistance in learning (Gullo et al., 2015). Study of student performance in gross anatomy indicated that scores on practical examinations could fulfill that function. Figure 6b is a plot of the number of students and the ranges of scores for practical examinations in Lower Extremity and Head and Neck for the years 2017–2019 (*n* = 242 students in 9 examinations). This plot shows a discrete group of students who did not achieve passing grades and the distribution of exam scores was strongly bimodal in some years. These data indicate that, despite the high performance levels, a subset of students needing additional assistance in learning can still be identified.

3.8 | Survey of effects of curricular changes on learning and stress

To gain an initial measure of students' views of the effectiveness of the curricular changes, a survey was distributed to students by email with questions related to (a) beneficial effects of the format of data presented as Clinical Symptom/Anatomy charts, (b) potential benefits of the format in preparation for the USMLE Step 1 examinations and (c) the overall effects on student stress. A histogram of student responses is shown in Figure 6c. The responses of students were quite positive about the curricular format: 90.2% of students strongly agreed/agreed that the clinical format of anatomy reduced stress (mean score 4.61 ± 0.97 *SD* of 5) and 95.1% felt that the format facilitated their preparation for the USMLE Step 1 examination (mean score 4.76 ± 0.54 *SD*).

4 | DISCUSSION

The goal of the pedagogical changes described in this article was to adapt teaching of gross anatomy/embryology to a compressed duration of instruction while still preparing students for licensing examinations and subsequent training in medicine. Two new approaches were utilized in the pedagogy and its evaluation: first, instruction was based upon correlating the symptoms associated with a core of clinical conditions with their structural and functional foundation in anatomy; second, an extended data base (2005–2019) was developed to evaluate these changes, based upon on examinations that included specific questions asked repetitively over a number of years (2012–2019), spanning the curricular revisions. The effects of these changes in instructional method and evaluation are discussed below.

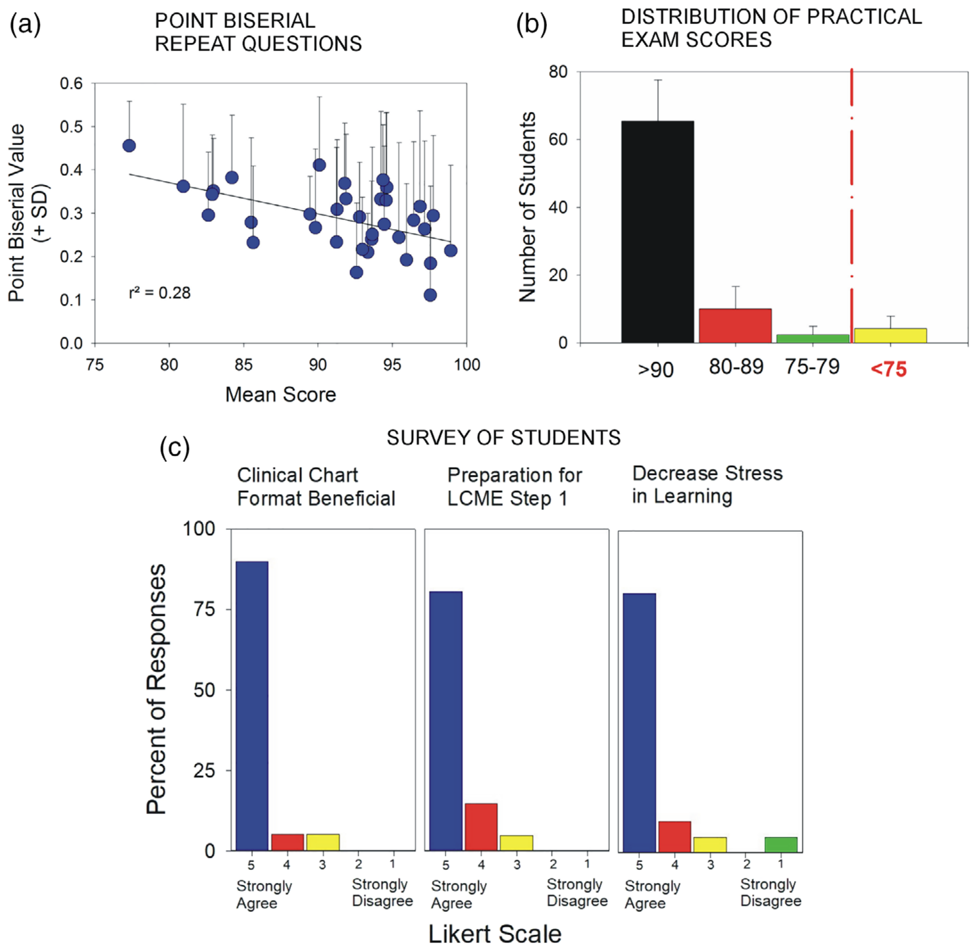

FIGURE 6 Quantification of repeat questions and survey of students—(a) Biserial values—This graph plots the mean point biserial values (+*SD*) for repeat questions in both the areas of Lower Extremity and Head and Neck. The point biserial values showed considerable variability and were only weakly correlated with the mean performance (r^2 = .28). (b) Bimodal distribution of exam scores—This histogram plots the distribution on practical exams scores (mean Lower Extremity and Head and Neck, years 2017–2019). The distribution is bimodal and indicates that, despite the high mean scores, these examinations can still be used to identify students having difficulty in gross anatomy. (c) Survey of students—These histograms show responses of students to a survey (in Likert format, 5 strongly agree, 1 strongly disagree) on the positive effects of clinical/anatomical format (left), evaluating preparation for the USMLE Step 1 examination (middle) and effectiveness in reducing stress in learning (right) [Color figure can be viewed at wileyonlinelibrary.com]

4.1 | Instruction based upon symptoms, not clinical cases

Instruction in anatomy was reorganized and based upon the symptoms of clinical conditions rather than full case studies (Fan, Jiang, Shi, Wang, & Li, 2018; Neville, 2009). The conditions were specifically associated with or directly resulted from changes in anatomy at a macroscopic level. Instruction based upon symptoms was a useful way to "parse out" learning, in a number of ways: (a) this method permitted development of a basic vocabulary and knowledge of the specific definitions of terms was stressed and reiterated in written and lecture material and in discussions; (b) the causes of selected clinical conditions could be immediately related to anatomy and provided a context for learning the structural organization of the body; (c) analysis of symptoms that reflect pathological or developmental changes permitted direct discussion of the relationship between structure and function. The change in instructional method represents a shift in emphasis rather than a novel approach as study of clinical symptoms is a component of many other pedagogies (Morton & Colbert-Getz, 2017; Neville, 2009). In addition, a number of schools have organized instruction within blocks based upon disease processes, although the utilization of clinical symptoms as a primary pedagogical method has not been explicitly stated (Halliday et al., 2015; Rizzolo et al., 2010; White et al., 2014).

4.2 | Advantage: Learning the vocabulary of medicine and reduction of student stress

Limiting discussion to the anatomical basis of symptoms had important advantages over pedagogies based upon complete clinical problems. The effectiveness and efficiency of problem-based approaches depend upon the background and prior training of the student, which have become increasingly diverse. Anatomy is a language that is essential in developing the vocabulary of clinical medicine (Al-Jamal, 2018; Bowen & ten Cate, 2017). Clinical terminology is highly specific and widely utilized because, as noted by Bowen and ten Cate (2017) it is efficient in describing complex concepts with combinations of features and provides uniformity in communications among physicians. However, the medical lexicon ("talking like a physician," Bowen & ten Cate, 2017, p. 49) is often only acquired in medical school while vocabulary instruction is rarely discussed in the medical education literature. For many students, medical terminology is effectively a "foreign" language and, in teaching at a primary or undergraduate level, language instruction typically begins by establishing and defining a vocabulary in simple contexts and then building up to complex thoughts (Larson, Dixon, & Townsend, 2013). In the present study, lectures often utilized a "word of the day" (e.g., hernia) and precisely defined its meaning (displacement of a structure from its normal position) (Kearney & Levine, 2019). This basic but essential element is often neglected in other formats, such as "flipped" lectures or independent learning. Omitting vocabulary instruction produces considerable disparity between students that have prior training and students who are stressed by the requirement of looking up and learning many terms, particularly if the volume of material is increased while the duration of learning is decreased.

It is also important to note that an inherent limitation in multiple-choice examinations (such as the USMLE Step 1) is that the questions provide all the words rather than relying upon the students to choose and assemble those words. Insufficient understanding of the meanings of words may not be assessed but could be manifested in clinical choices later in training and practice (Hołda et al., 2019). In addition, repetition of presentation of clinical content (repeated case studies) does not insure comprehension of vocabulary. The duration of older, semester-length courses in Anatomy was effective in providing the repetition needed for language acquisition.

The survey that we distributed indicated that students perceive these changes as effectively preparing them for the LCME Step 1 examination. Furthermore, although responses were more diverse, a majority of students indicated that the format adopted reduced stress in learning. We plan to repeat and extend this survey in future years but, even within the limitations of parametric analysis of the Likert format (Sullivan & Artino, 2013), these data provide support for the idea that a Clinical/Anatomical approach and reduction of detail in initial learning can mitigate the deleterious effects of student stress (Dyrbye et al., 2019).

4.3 | Disadvantage: Elimination/reduction of content in anatomy

The decrease in duration of instruction presented a considerable obstacle to students' retaining the details of body structure. The retention of rote memorization has long been known to be strongly dependent upon the duration of study and spacing of instruction (Delaney, Godbole, Holden, & Chang, 2018; Dempster, 1988; Larsen, 2018; Morin et al., 2019). To adapt to the decreased duration of instruction (6 days for Lower Extremity) learning of muscle anatomy was reduced (only actions/innervations, not origins/insertions). Although this had an immediate benefit in decreasing the informational load, it proved to be a "two-edged sword," as students reported difficulty of initial identification of muscles in laboratory dissection, which is based upon muscle origin/insertion as well as position. Also, learning of origins and insertions was still required for some muscles when that provided insight into the symptoms of clinical syndromes (e.g., Gluteal gait). However, knowledge of muscle actions and innervations still provided understanding of the relationship between muscle structure/function and also facilitated understanding of syndromes of nerve damage (Ghosh, 2017; Miller, Perrotti, Silverthorn, Dalley, & Rarey, 2002).

Detail in content was also decreased in teaching of the circulatory system by requiring learning only arterial branches of major clinical relevance (ex only meningeal branches of the maxillary artery). However, identification of all branches was still required in laboratory dissection and in the interpretation and testing of arterial angiograms. It is important to note that, concomitant with the decline in anatomy teaching, there has been a dramatic increase in the use and informational content of imaging techniques that require a detailed knowledge of three-dimensional body structure, although questions based upon images of anatomy have apparently been reduced in the USMLE Step 1 examination.

The reduction of content in anatomy may clearly be an impediment to a number of aspects of medical education, particularly training in specialties in which knowledge of anatomical detail is essential (e.g., orthopedics, surgery, neurosurgery, radiology). This could be resolved through supplementary instruction in more advanced courses in Anatomy introduced later into the curricula (Blunt & Blizard, 1975). This was not reflected in test scores in the present study, as questions related to deleted content were also eliminated in assessment.

4.4 | Analysis of performance using an extended baseline and "repeat" questions

The multiyear database of student exam scores indicated that student performance in gross anatomy remained high even after curriculum changes that increased the number of courses taught simultaneously. The development of long-term databases is important as errors in analysis of test scores may occur when performance is evaluated over a limited period (Gullo, 2016). Many older studies examined data over single or two year periods (e.g., Minhas, Ghosh, & Swanzy, 2012; Zhang, Fenderson, Schmidt, & Veloski, 2013). The differences in performance may not only reflect changes in pedagogy but other, more complex parameters that are only apparent when data are evaluated over longer time periods (e.g., Nieder & Borges, 2012). This is particularly important in comparing some forms of assessment, such as practical examinations, that are inherently variable as they often use student dissections as test material (discussed by Yaqinuddin, Zafar, Ikram, & Ganguly, 2013). These errors may not be apparent but may be detected if data are acquired and evaluated over longer time periods.

More specific analysis was possible using the subset of repeat questions (Joncas et al., 2018). As the goal was to optimize and assess establishment of a basic foundation of gross anatomy and the medical vocabulary, no changes were made to make these questions more discriminative. Analysis of test scores after introduction of the use of repeat questions showed small variations in performance that paralleled the scores on nonrepeat questions, indicating that students had no prior knowledge of question repetition (Wood, 2009). Changes were made in the text and distractors for some questions to insure their reliability (Deepak, Al-Umran, Al-Sheikh, Dkoli, & Al-Rubaish, 2015) but no consistent changes in performance were found after these changes. Consistently high performance was also evident in student scores on practical examinations which can test some aspects of anatomical knowledge more directly than written multiple choice tests (Ghosh, 2017; Schuwirth & van der Vleuten, 2004). In addition, we did not attempt to correlate these results with subsequent performance on USMLE Step 1 examinations as those tests are limited in their assessment of knowledge of anatomy and do not include item analysis of topics that could be specifically related to our curricular changes. However, the sustained performance of students in repeat questions and practical examinations supports the conclusion that the pedagogical changes were effective in establishing a base of knowledge of anatomy even in a decrease period of instruction.

4.5 | Multimodal pedagogies

An important element in sustaining student performance in gross anatomy in a compressed duration was the use of multimodal pedagogies to reiterate terminology and increase the depth of knowledge of body structure. The benefit of use of diverse methods of instruction has now been demonstrated in a wide variety of studies (Estai & Bunt, 2016; Hu, Wattchow, & de Fontgalland, 2018; Klement et al., 2017; Johnson et al., 2012; Moro, Smith, & Stromberga, 2019). In the present study, both "flipped" and conventional lectures presented the same anatomical structures repeatedly in photographs and diagrams, as well as radiographic (X-ray), radiological (CT) and MRI images. In addition, "active" learning regularly was utilized as many of the same structures were then dissected in laboratory sessions, often on the same day (Ghosh, 2017). Laboratory sessions were essential in developing appreciation for anatomical variation. Spacing of repetition was also aided by subsequent small group laboratory review sessions that occurred prior to each examination.

These multimodal methods facilitated learning by students with diverse backgrounds, as evidence by the high performance on both written and practical examinations. Student feedback in course evaluations regularly cited these approaches as making subjects "easier to understand." In contrast, use of single pedagogies such as problem-solving or team based learning approaches have potential benefits in developing student cognition but at the expense of increasing stress (White et al., 2014). While changes in methods of assessment have been indicated to improve student well-being (Bloodgood, Short, Jackson, & Martindale, 2009; Wilkinson, 2011) there have been few proposals for changes in pedagogy to reduce stress (D'Eon, 2014; Lyndon et al., 2017). The present study suggests that establishing and directly assessing a vocabulary and base of anatomical knowledge can facilitate learning that can be applied to more complex clinical problems, with a concomitant and overall decrease in stress.

4.6 | Early identification of students needing assistance in learning

A goal of this study was to examine whether performance in gross anatomy could be used to identify students needing assistance in learning. Analysis of examination scores showed that, despite high overall performance levels, it was possible to consistently identify a discrete group that had not achieved a passing grade. The specific causes of difficulties encountered by some students are unclear but may reflect their academic background and the lack prior training in Anatomy, which can impede acquisition of steric knowledge and formation of an internalized image of body structure needed for interpretation of radiographs, CT and MRI images (Houser & Kondrashov, 2018; Wish-Baratz, Gubatina, Enterline, & Griswold, 2019; Zill, 2016). Our school has developed methods for identification of students needing assistance in learning and the present results suggest that analysis of early performance in gross anatomy may be of value in that process (Gullo et al., 2015).

4.7 | Limitations of this study

"Ceiling Effect"—Student scores on recent gross anatomy tests were high (increasing from averages in the high 80s to low 90s) and potentially subject to a "ceiling effect" (Taylor, 2012), limiting their applicability in discriminating performance among students who achieve a passing grade (Cramer & Howitt, 2005). Ranking student performance was not our goal as our method has been to establish a core of knowledge and assess performance through questions that are criterion-referenced (evaluating a specific body of anatomical knowledge as a fixed criterion) rather than norm referenced (assessing differences in abilities among test-takers) (Glaser, 1963). Due to the changes in our pedagogy, examinations have essentially become screening or threshold tests rather than rating tools, with the goal of aiding students in establishing a base of knowledge of the anatomical basis of clinical medicine which could then be expanded in further training (Shepard, 2018). While scores prior to 2016 showed normal distributions, analysis of repeat questions required use of nonparametric tests that do not require normal distributions (e.g., Wilcoxon test) to demonstrate that performance was consistent. In addition, a significant but small percentage of students did not pass these tests, indicating that some individuals found them challenging. We plan to re-evaluate the repeat questions (Boone, 2016) to increase our ability to identify students needing assistance in learning by increasing the number of clinical conditions studied and by introducing other measures of assessment, such as grading laboratory dissections (Nwachukwu, Lachman, & Pawlina, 2015). Use of multiple metrics of assessment has been suggested as a method increasing the reliability of pass/fail examinations (Möltner, Tımbıl, & Jünger, 2015) and has also been discussed as applicable to the consequences of the proposed changes in the USMLE Step 1 examination to a pass/fail format (Swails, Aibana, & Stoll, 2019).

Limitations of observational studies—In addition, this article was an observational study done without a control group (Rosenbaum, 2009), due mainly to constraints in the number of anatomy faculty. Although this study has shown that student performance was consistently high and did not decrease through curricular changes that compressed the duration of gross anatomy instruction, we did not demonstrate a direct correlation between the modifications of pedagogy and test scores, as the teaching methods were applied to all students. The accuracy of measurement of changes in knowledge of anatomy was aided by the use of repeat questions over an eight-year period, which eliminated variations due to question format, distractors, etc. and supported by the finding that comparable changes occurred in both written and practical examinations (McKillip, 1992). We believe that the consistency (not improvement) in those data support the idea that instruction in gross anatomy was effective despite the compression of duration. In addition, comparison of block exam scores in Head and Neck and Lower Extremity with assessment of teaching of anatomy in other regions, in which pedagogy was not comparably changed, supports the idea that methods we used were beneficial. However, further confirmation is needed and studies are planned to assess the effects of integration by other methods, such as tests of retention of anatomical knowledge in students at more advanced stages of undergraduate training.

Last, we also plan to repeat and expand the survey on student stress to confirm the effects of curricular changes on student well-being and to correlate the effects with specific pedagogical methods.

In sum, we believe our data support the idea that pedagogical changes can be effective in teaching gross anatomy in a limited time frame and these methods may benefit others confronting the changes in anatomy instruction in medical education.

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REFERENCES

AAMC-HHMI. (2009). *Association of American Medical Colleges—Howard Hughes Medical Institute. Report of the Scientific Foundations for Future Physicians (SFFP) Committee*. Washington, DC: Association of American Medical Colleges.

Al-Jamal, D. A. (2018). The role of linguistic clues in medical students' reading comprehension. *Psychology Research and Behavior Management*, *11*, 395–401. https://doi.org/10.2147/PRBM.S174087

Bains, M., & Kaliski, D. Z. (2020). An anatomy workshop for improving anatomy self-efficacy and competency when transitioning into a problem-based learning, Doctor of Physical Therapy program. *Advances in Physiology Education*, *44*, 39–49. https://doi.org/10.1152/advan.00048.2019

Bergman, E. M., Prince, K. J., Drukker, J., van der Vleuten, C. P., & Scherpbier, A. J. (2008). How much anatomy is enough? *Anatomical Sciences Education*, *1*, 184–188.

Bloodgood, R., Short, J., Jackson, J., & Martindale, J. (2009). A change to pass/fail grading in the first two years at one medical school results in improved psychological wellbeing. *Academic Medicine*, *84*, 655–662.

Blunt, M. J., & Blizard, P. J. (1975). Recall and retrieval of anatomical knowledge. *British Journal of Medical Education*, *9*, 255–263.

Boone, W. J. (2016). Rasch analysis for instrument development: Why, when, and how? *CBE Life Sciences Education*, *15*, 4–7. https://doi.org/10.1187/cbe.16-04-0148

Bowen, J. L., & ten Cate, O. (2017, 2018). Prerequisites for learning clinical reasoning. In O. ten Cate, E. J. F. M. Custers, & S. J. Durning (Eds.), *Principles and practice of case-based clinical reasoning education: A method for preclinical students* (pp. 47–63). Cham, CH: Springer.

Brooks, W. S., Woodley, K. T., Jackson, J. R., & Hoesley, C. J. (2015). Integration of gross anatomy in an organ system-based medical curriculum: Strategies and challenges. *Anatomical Sciences Education*, *8*, 266–274. https://doi.org/10.1002/ase.1483

Burk-Rafel, J., Santen, S. A., & Purkiss, J. (2017). Study behaviors and USMLE step 1 performance: Implications of a student self-directed parallel curriculum. *Academic Medicine*, *92*, S67–S74.

Chaudhry, H. J., Katsufrakis, P. J., & Tallia, A. F. (2020). The USMLE step 1 decision: An opportunity for medical education and training. *Journal of the American Medical Association*, *323*, 2017–2018. https://doi.org/10.1001/jama.2020.3198

Clunie, L., Morris, N. P., Joynes, V. C., & Pickering, J. D. (2018). How comprehensive are research studies investigating the efficacy of technology-enhanced learning resources in anatomy education? A systematic review. *Anatomical Sciences Education*, *11*, 303–319. https://doi.org/10.1002/ase.1762

Committee to Evaluate the USMLE Program (CEUP). (2020). *Comprehensive review of USMLE: Summary of the final report and recommendations*. Retrieved from https://www.usmle.org/pdfs/cru/CEUP-Summary-Report-June2008.pdf

Cramer, D., & Howitt, D. L. (2005). *The SAGE dictionary of statistics: A practical resource for students in the social sciences* (p. 21). Thousand Oaks, CA: SAGE. ISBN 978-0-7619-4138-5.

Cuddy, M. M., Swanson, D. B., Drake, R. L., & Pawlina, W. (2013). Changes in anatomy instruction and USMLE performance: Empirical evidence on the absence of a relationship. *Anatomical Sciences Education, 6*, 3–10.

Deepak, K. K., Al-Umran, K. U., Al-Sheikh, M. H., Dkoli, B. V., & Al-Rubaish, A. (2015). Psychometrics of multiple choice questions with non-functioning distracters: Implications to medical education. *Indian Journal of Physiology and Pharmacology*, *59*, 428–435.

Delaney, P. F., Godbole, N. R., Holden, L. R., & Chang, Y. (2018). Working memory capacity and the spacing effect in cued recall. *Memory*, *26*, 784–797. https://doi.org/10.1080/09658211

Dempster, F. N. (1988). The spacing effect: A case study in the failure to apply psychology research. *American Psychologist*, *43*, 627–634.

D'Eon, M. (2014). Is medical education hazardous to your health? *Canadian Medical Education Journal*, *5*, e1–e4.

Drake, R. L. (2014). A retrospective and prospective look at medical education in the United States: Trends shaping anatomical sciences education. *Journal of Anatomy*, *224*, 256–260.

Drake, R. L., McBride, J. M., Lachman, N., & Pawlina, W. (2009). Medical education in the anatomical sciences: The winds of change continue to blow. *Anatomical Sciences Education*, *2*, 253–259.

Dyrbye, L. N., Lipscomb, W., & Thibault, G. (2019). Redesigning the learning environment to promote learner well-being and professional development. *Academic Medicine*, *5*, 674–678. https://doi.org/10.1097/ACM.0000000000003094

Dyrbye, L. N., Thomas, M. R., & Shanafelt, T. D. (2005). Medical student distress: Causes, consequences, and proposed solutions. *Mayo Clinic Proceedings*, *80*, 1613–1622.

Estai, M., & Bunt, S. (2016). Best teaching practices in anatomy education: A critical review. *Annals of Anatomy*, *208*, 151–157. https://doi.org/10.1016/j.aanat.2016.02.010

Fan, C., Jiang, B., Shi, X., Wang, E., & Li, Q. (2018). Update on research and application of problem-based learning in medical science education. *Biochemistry and Molecular Biology Education*, *46*, 186–194. https://doi.org/10.1002/bmb.21105

Farey, J. E., Bui, D. T., Townsend, D., Sureshkumar, P., Carr, S., & Roberts, C. (2018). Predictors of confidence in anatomy knowledge for work as a junior doctor: A national survey of Australian medical students. *BMC Medical Education*, *18*, 174. https://doi.org/10.1186/s12909-018-1280-5

Findlater, G. S., Kristmundsdottir, F., Parson, S. H., & Gillingwater, T. H. (2012). Development of a supported self-directed learning approach for anatomy education. *Anatomical Sciences Education*, *5*, 114–121.

Ghosh, S. K. (2017). Cadaveric dissection as an educational tool for anatomical sciences in the 21st century. *Anatomical Sciences Education*, *10*, 286–299. https://doi.org/10.1002/ase.1649

Glaser, R. (1963). Instructional technology and the measurement of learning outcomes. *The American Psychologist*, *18*, 519–521. https://doi.org/10.1037/h004929

Gullo, C., McCarthy, M., Shapiro, J., & Miller, B. (2015). Predicting medical student success on licensure exams. *Medical Science Educator*, *25*, 447–453. https://doi.org/10.1007/s40670-015-0179-6

Gullo, C. A. (2016). The future is in the numbers: The power of predictive analysis in the biomedical educational environment. *Medical Education Online*, *21*, 32516. https://doi.org/10.3402/meo.v21.32516

Halliday, N., O'Donoghue, D., Klump, K. E., & Thompson, B. (2015). Human structure in six and one-half weeks: One approach to providing foundational anatomical competency in an era of compressed medical school anatomy curricula. *Anatomical Sciences Education*, *8*, 149–157. https://doi.org/10.1002/ase.1476

Hill, M. R., Goicochea, S., & Merlo, L. J. (2018). In their own words: Stressors facing medical students in the millennial generation. *Medical Education Online*, *23*, 1530558. https://doi.org/10.1080/10872981

Hinduja, K., Samuel, R., & Mitchell, S. (2005). Problem-based learning: Is anatomy a casualty? *The Surgeon*, *3*, 84–87.

Hołda, K. M., Stefura, T., Koziej, M., Skomarovska, O., Jasińska, K. A., Sałabun, W., & Klimek-Piotrowska, W. (2019). Alarming decline in recognition of anatomical structures amongst medical students and physicians. *Annals of Anatomy – Anatomischer Anzeiger*, *221*, 48–56. https://doi.org/10.1016/j.aanat.2018.09.004

Houser, J. J., & Kondrashov, P. (2018). Gross anatomy education today: The integration of traditional and innovative methodologies. *Missouri Medicine*, *115*, 61–65.

Hu, M., Wattchow, D., & de Fontgalland, D. (2018). From ancient to avant-garde: A review of traditional and modern multimodal approaches to surgical anatomy education. *ANZ Journal of Surgery*, *88*, 146–151. https://doi.org/10.1111/ans.14189

Humphrey, H. J., & Woodruff, J. N. (2020). The pass/fail decision for USMLE step 1—Next steps. *Journal of the American Medical Association*, *323*, 2022–2023. https://doi.org/10.1001/jama.2020.3938

Irby, D. M., Cooke, M., & O'Brien, B. C. (2010). Calls for reform of medical education by the Carnegie Foundation for the Advancement of Teaching: 1910 and 2010. *Academic Medicine*, *85*, 220–227.

Jackson, E. R., Shanafelt, T. D., Hasan, O., Satele, D. V., & Dyrbye, L. N. (2016). Burnout and alcohol abuse/dependence among U.S. medical students. *Academic Medicine*, *91*, 1251–1256. https://doi.org/10.1097/ACM.0000000000001138

Johnson, E. O., Charchanti, A. V., & Toupis, T. G. (2012). Modernization of an anatomy class: From conceptualization to implementation. A case for integrated multimodal-multidisciplinary teaching. *Anatomical Sciences Education*, *5*, 354–366.

Joncas, S. X., St-Onge, C., Bourque, S., & Farand, P. (2018). Re-using questions in classroom-based assessment: An exploratory study at the undergraduate medical education level. *Perspectives on Medical Education*, *7*, 373–378. https://doi.org/10.1007/s40037-018-0482-1

Kamei, R. K., Cook, S., Puthucheary, J., & Starmer, C. F. (2012). 21st century learning in medicine: Traditional teaching versus team-based learning. *Medical Science Educator*, *22*, 57–64.

Kearney, M. S., & Levine, P. B. (2019). Early childhood education by television: Lessons from sesame street. *American Economic Journal: Applied Economics*, *11*, 318–350. https://doi.org/10.1257/app.20170300318

Kerby, J., Shukur, Z. N., & Shalhoub, J. (2011). The relationships between learning outcomes and methods of teaching anatomy as perceived by medical students. *Clinical Anatomy*, *24*, 489–497.

Klement, B. J., Paulsen, D. F., & Wineski, L. E. (2011). Anatomy as the backbone of an integrated first year medical curriculum: Design and implementation. *Anatomical Sciences Education*, *4*, 157–169.

Klement, B. J., Paulsen, D. F., & Wineski, L. E. (2017). Implementation and modification of an anatomy-based integrated curriculum. *Anatomical Sciences Education*, *10*, 262–275. https://doi.org/10.1002/ase.1676

Koles, P. G., Stolfi, A., Borges, N. J., Nelson, S., & Paremelee, D. X. (2010). The impact of team-based learning on medical students' academic performance. *Academic Medicine*, *85*, 1739–1745.

Kumar, A. D., Shah, M. K., Maley, J. H., Evron, J., Gyftopoulos, A., & Miller, C. (2015). Preparing to take the USMLE step 1: A survey on medical students' self-reported study habits. *Postgraduate Medical Journal*, *91*, 257–261.

Laitman, B. M., & Muller, D. (2019). Medical student deaths by suicide: The importance of transparency. *Academic Medicine*, *94*, 466–468. https://doi.org/10.1097/ACM.0000000000002507

Larsen, D. P. (2018). Planning education for long-term retention: The cognitive science and implementation of retrieval practice. *Seminars in Neurology*, *38*, 449–456. https://doi.org/10.1055/s-0038-1666983

Larson, L., Dixon, T., & Townsend, D. (2013). How can teachers increase classroom use of academic vocabulary? *Voices from the Middle*, *20*, 16–21.

Lyndon, M. P., Henning, M. A., Alyami, H., Krishna, S., Yu, T. C., & Hill, A. G. (2017). The impact of a revised curriculum on academic motivation, burnout, and quality of life among medical students. *Journal of Medical Education and Curricular Development*, *31*(4), 2382120517721901. https://doi.org/10.1177/2382120517721901

Mazur, E. (2009). Education. Farewell, lecture? *Science*, *323*, 50–51.

McBride, J. M., & Drake, R. L. (2018). National survey on anatomical sciences in medical education. *Anatomical Sciences Education*, *11*, 7–14.

McGaghie, W. C., Cohen, E. R., & Wayne, D. B. (2011). Are United States medical licensing exam step 1 and 2 scores valid measures for postgraduate medical residency selection decisions? *Academic Medicine*, *86*, 48–52.

McKeown, P. P., Heylings, D. J., Stevenson, M., McKelvey, K. J., Nixon, J. R., & McCluskey, D. R. (2003). The impact of curricular change on medical students' knowledge of anatomy. *Medical Education*, *37*, 954–961.

McKillip, J. (1992). Research without control groups: A control construct design. In F. B. Bryant, J. Edwards, R. S. Tindale, E. J. Posavac, L. Heath & E. Henderson-King (Eds.), *Social psychological applications to social issues, Vol. 2. Methodological issues in applied social psychology* (pp. 159–175). New York: Springer. https://doi.org/10.1007/978-1-4899-2308-0_8

Miller, S. A., Perrotti, W., Silverthorn, D. U., Dalley, A. F., & Rarey, K. E. (2002). From college to clinic: Reasoning over memorization is key for understanding anatomy. *The Anatomical Record*, *269*, 69–80.

Minhas, P. S., Ghosh, A., & Swanzy, L. (2012). The effects of passive and active learning on student preference and performance in an undergraduate basic science course. *Anatomical Sciences Education*, *5*, 200–207.

Möltner, A., Tımbıl, S., & Jünger, J. (2015). The reliability of the pass/fail decision for assessments comprised of multiple components. *GMS Zeitschrift für Medizinische Ausbildung*, *32*, Doc42. https://doi.org/10.3205/zma000984

Morin, C. E., Hostetter, J. M., Jeudy, J., Kim, W. G., McCabe, J. A., Merrow, A. C., … Kim, J. S. (2019). Spaced radiology: Encouraging durable memory using spaced testing in pediatric radiology. *Pediatric Radiology*, *49*, 990–999. https://doi.org/10.1007/s00247-019-04415-3

Moro, C., Smith, J., & Stromberga, Z. (2019). Multimodal learning in health sciences and medicine: Merging technologies to enhance student learning and communication. *Advances in Experimental Medicine and Biology*, *1205*, 71–78. https://doi.org/10.1007/978-3-030-31904-5_5

Morton, D. A., & Colbert-Getz, J. M. (2017). Measuring the impact of the flipped anatomy classroom: The importance of categorizing an assessment by Bloom's taxonomy. *Anatomical Sciences Education*, *10*, 170–175. https://doi.org/10.1002/ase.1635

Neville, A. J. (2009). Problem-based learning and medical education forty years on: A review of its effects on knowledge and clinical performance. *Medical Principles and Practice*, *18*, 1–9. https://doi.org/10.1159/000163038

Nieder, G. L., & Borges, N. J. (2012). An eight-year study of online lecture use in a medical gross anatomy and embryology course. *Anatomical Sciences Education*, *5*, 311–320.

Nwachukwu, C., Lachman, N., & Pawlina, W. (2015). Evaluating dissection in the gross anatomy course: Correlation between quality of laboratory dissection and students outcomes. *Anatomical Sciences Education*, *8*, 45–52. https://doi.org/10.1002/ase.1458

Papa, V., & Vaccarezza, M. (2013). Teaching anatomy in the XXI century: New aspects and pitfalls. *Scientific World Journal*, *2013*, 310348–310345. https://doi.org/10.1155/2013/310348

Prober, C. G., & Heath, C. (2012). Lecture halls without lectures – A proposal for medical education. *The New England Journal of Medicine*, *388*, 1657–1659.

Rizzolo, L. J., Rando, W. C., O'Brien, M. K., Haims, A. H., Abrahams, J. J., & Stewart, W. B. (2010). Design, implementation, and evaluation of an innovative anatomy course. *Anatomical Sciences Education*, *3*, 109–120.

Rosenbaum, P. R. (2009). *Design of observational studies*. New York: Springer. ISBN 10:1441912126, ISBN-13:978-1441912121.

Sbayeh, A., Qaedi Choo, M. A., Quane, K. A., Finucane, P., McGrath, D., O'Flynn, S., … O'Tuathaigh, C. M. (2016). Relevance of anatomy to medical education and clinical practice: Perspectives of medical students, clinicians, and educators. *Perspectives on Medical Education*, *5*, 338–346.

Schuwirth, L. W., & van der Vleuten, C. P. (2004). Different written assessment methods: What can be said about their strengths and weaknesses? *Medical Education*, *38*, 974–979.

Schwartz, C. C., Ajjarapu, A. S., Stamy, C. D., & Schwinn, D. A. (2018). Comprehensive history of 3-year and accelerated US medical school programs: A century in review. *Medical Education Online*, *23*, 1530557.

Shepard, L. A. (2018). Learning progressions as tools for assessment and learning. *Applied Measurement in Education*, *31*, 165–174.

Slavin, S. J., Schindler, D. L., & Chibnall, J. T. (2014). Medical student mental health 3.0: Improving student wellness through curricular changes. *Academic Medicine*, *89*, 573–577.

Sugand, K., Abrahams, P., & Khurana, A. (2010). The anatomy of anatomy: A review for its modernization. *Anatomical Sciences Education*, *3*, 83–93.

Sullivan, G. M., & Artino, A. R. (2013). Analyzing and interpreting data from Likert-type scales. *Journal of Graduate Medical Education*, *5*, 541–542.

Swails, J. L., Aibana, O., & Stoll, B. J. (2019). The conundrum of the United States medical licensing examination score reporting structure. *Journal of the American Medical Association*, *322*, 605–606.

Taylor, T. J. (2012). Ceiling effect. In N. J. Salkind (Ed.), *Encyclopedia of research design* (pp. 133–134). Thousand Oaks, CA: Sage Publications. https://dx.doi.org/10.4135/9781412961288

Vasan, N. S., DeFouw, D. O., & Compton, S. (2011). Team-based learning in anatomy: An efficient, effective, and economical strategy. *Anatomical Sciences Education*, *4*, 333–339.

White, C., Bradley, E., Martindale, J., Roy, P., Kunal, P., Yoon, M., & Worden, M. K. (2014). Why are medical students 'checking out' of active learning in a new curriculum? *Medical Education*, *48*, 315–324.

Wilkinson, T. (2011). Pass/fail grading: Not everything that counts can be counted. *Medical Education*, *45*, 860–862.

Willey, J. M., Lim, Y. S., & Kwiatkowski, T. (2018). Modeling integration: Co-teaching basic and clinical sciences medicine in the classroom. *Advances in Medical Education and Practice*, *9*, 739–751. https://doi.org/10.2147/AMEP.S169740

Wilson-Anstey, E., Lambert, W. M., & Krog, H. (2019). Wellness for all: Diversity, challenges, and opportunities to improve wellness for medical students. In D. Zappetti & J. Avery (Eds.), *Medical student well-being* (pp. 125–153). New York: Springer.

Wish-Baratz, S., Gubatina, A. P., Enterline, R., & Griswold, M. A. (2019). A new supplement to gross anatomy dissection: HoloAnatomy. *Medical Education*, *53*, 522–523. https://doi.org/10.1111/medu.13845

Wood, T. J. (2009). The effect of reused questions on repeat examinees. *Advances in Health Sciences Education: Theory and Practice*, *14*, 465–473. https://doi.org/10.1007/s10459-008-9129-z

Yammine, Y. (2014). The current status of anatomy knowledge: Where are we now? Where do we need to go and how do we get there? *Teaching and Learning in Medicine*, *26*, 184–188. https://doi.org/10.1080/10401334.2014.883985

Yaqinuddin, A., Zafar, M., Ikram, M. F., & Ganguly, P. (2013). What is an objective structured practical examination in anatomy? *Anatomical Sciences Education*, *6*, 125–133.

Zhang, G., Fenderson, B. A., Schmidt, R. R., & Veloski, J. J. (2013). Equivalence of students' scores on timed and untimed anatomy practical examinations. *Anatomical Sciences Education*, *6*, 281–285.

Zill, S. N. (2016). Performance in gross anatomy and identification of students needing assistance/guidance in learning. *The FASEB Journal*, *30*, lb7.

Zill, S. N. (2019). Rethinking anatomy: Clinical syndromes as the basis for teaching basic science in gross anatomy. *The FASEB Journal*, *32*, lb103.

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