

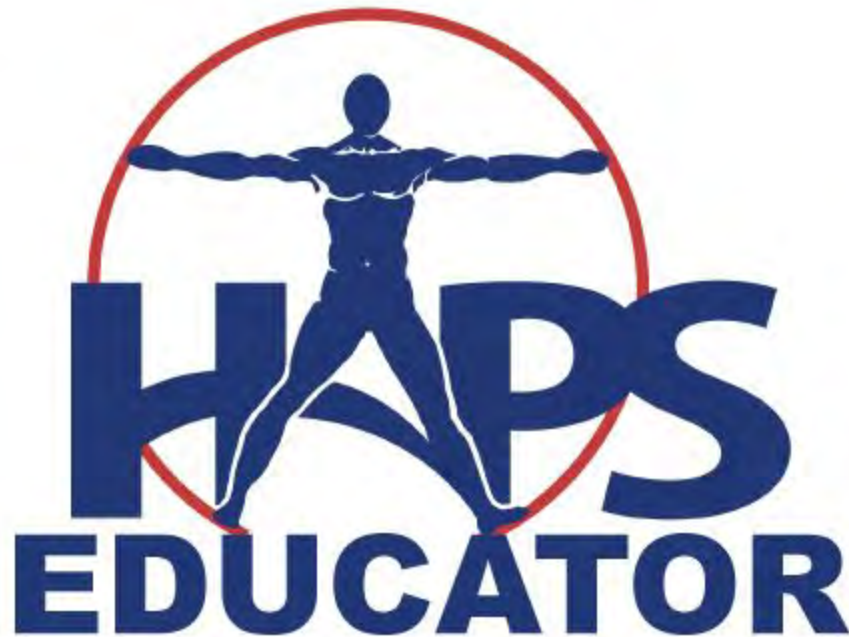
**Multimodal Review Sessions for Undergraduate Muscle  
Anatomy**

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# Multimodal Review Sessions for Undergraduate Muscle Anatomy

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## Abstract

Engagement of multiple learning modalities has been shown to promote learning. This study aimed to develop resources for anatomical sciences educators interested in adding additional teaching modalities into their repertoire. Three review sessions were created for the muscle anatomy unit of an undergraduate anatomy and physiology course, each designed to engage a different learning modality. The first session was a kinesthetic experience in which students were cued through a sequence of body positions similar to yoga poses with instruction of muscle anatomy relevant to each position. The second session was a tactile experience in which students were instructed how to shape clay into models of muscles and place them on a corresponding plastic skeleton. The third session was an audience-response question and answer (Q&A) session in which students responded to questions and received feedback about their performance. Each of the three review sessions was successfully implemented in a large undergraduate course with 445 total students. The authors encourage other anatomy educators to adapt these sessions for use in their own teaching. <https://doi.org/10.21692/haps.2021.022>

**Key words:** multimodal, muscle, anatomy, kinesthetic, tactile

## Introduction/Background

Learning science is a source of inspiration for educators who seek to better facilitate student learning and those who are interested in innovative educational approaches. In our anatomy program we became interested in the concept of learning modalities and the design of educational strategies utilizing non-traditional modalities. This paper details the theoretical basis of our investigation and how it led to our design and implementation of three muscle anatomy review sessions, each designed around different learning modalities.

In Mayer's cognitive theory of multimedia learning, learning is defined as an active process of filtering, selecting, organizing, and integrating information based upon prior knowledge (Mayer 2009). This information is delivered to the learner through learning modalities, which Moreno and Mayer define as a "sense system used by which the learner receives [learning] material" (Moreno and Mayer 2007). The authors identify auditory and visual modalities, which correspond to the senses of hearing and sight, respectively. Moreno and Mayer go on to state that, "According to the modality principle of instructional design, the most effective learning environments are those that combine verbal and non-verbal representations of the knowledge using mixed-modality presentations" (Moreno and Mayer, 2007). The combination of visual and verbal information, i.e. a lecture

slideshow with associated commentary, is the best described multimodal learning approach with the most evidence to its general effectiveness (Clark and Paivio 1991; Mayer and Sims 1994; Sadoski 2006).

Mayer's cognitive theory of multimedia learning asserts that human working memory is informed by multiple sensory modalities, each of which has a limited capacity of processing information (Mayer 2005; Mayer et al. 2001). According to this theory, educators who engage multiple senses with non-redundant and non-overwhelming information can better engage working memory and promote better learning. Mayer focused on the dual channels of visual/pictorial and auditory/verbal processing in his research; however, the contribution of other sensory modalities to learning remains an open research area. Modality is used herein to indicate various avenues of content distribution apart from or in addition to visual (such as a digitally projected lecture slide) and apart from auditory (a lecturer vocalizing information) approaches.

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The physical and universal nature of anatomy makes it a topic well suited to incorporating modalities of student learning beyond the visual and auditory modalities typically engaged in lectures. All students of human anatomy possess a human body and experience that body through not only visual and verbal senses, but also through tactile sensation and proprioception. This common experience of an individual's body is perhaps why innovative multimedia strategies for teaching anatomy abound. Sculpting or working with clay models (Bareither et al. 2013; DeHoff et al. 2011; Haspel et al. 2014; Kooloos et al. 2014; Oh et al. 2009; Waters et al. 2005), engaging in yoga/Pilates activities (Bentley and Pang 2012; McCulloch et al. 2010), body painting (McMenamin 2008), and engaging with virtual reality (Seo et al. 2017) are examples of innovative anatomy teaching strategies recently described in the educational literature.

A common theme to this innovative anatomy education literature is the engagement of proprioception and/or somatosensation to convey spatial information. Similar to a lecture format, these modalities can be delivered simultaneously with verbally-delivered auditory information. Delivering anatomical education using the multiple learning modalities with which we experience our own bodies may prove to have advantages over typical lectures including increased student engagement, efficient communication of nuanced physical relationships, and expanded associations of anatomical concepts and terminology. However, there is limited literature that describes the practical implementation of alternative learning modalities for anatomy for large (e.g.  $n > 100$ ) courses.

The authors undertook this pilot study in order to investigate the feasibility of applying these alternative modalities in an undergraduate anatomy and physiology course. Three review sessions of the same muscle anatomy unit, each designed to engage different sensory modalities, were implemented in a large undergraduate anatomy and physiology course following the lecture series that introduced muscle anatomy. Furthermore, outlines of the educational resources developed in this study are included as tables to enable their use and adaptation by anatomical sciences educators interested in incorporating multimodal sessions into their own teaching.

## Methods

This study was performed as a part of a large (445 students) undergraduate anatomy and physiology course that included lecture and laboratory components. The majority of the study population consisted of first-year college students who were taking the course as a prerequisite for nursing school. The remaining enrollees in the course were students of kinesiology, health promotion, and pre-physical therapy majors. This study took place during the first semester of a two-semester anatomy and physiology sequence during the muscle anatomy unit.

Students pre-selected their preferred review session using a learning management system (Canvas, Instructure Inc., Salt Lake City, Utah) poll. The purpose of pre-selecting the activity of their choice was to give the instructors the opportunity to prepare appropriately-sized teaching space based on the estimated number of participants. The same instructor completed all three sessions of each modality; i.e. A.W. completed all three Q&A sessions, L.W. completed all three kinesthetic sessions, and K.P. completed all three tactile sessions. At the time, A.W. was a PhD candidate working as a teaching assistant in the course, L.W. was staff at the University otherwise unaffiliated with the course apart from this collaboration, and K.P. was an Assistant Professor and director of the course. No additional teaching assistants or other facilitators were involved.

The kinesthetic review session was held in a group exercise room in the campus recreation facility. Students were asked to wear clothing appropriate for the activity and were provided with a yoga mat that was loaned to them by the campus recreation facility. The instructor demonstrated movements at the front of the room, provided verbal cues for the movement, and verbally reviewed the muscles and attachments involved in the actions. Students followed along with the demonstrated movements and were encouraged to later study for the examination by reviewing the digitally provided review guide and recalling to memory and practicing the activities completed as a group. An outline of the movement sequence is provided in Table 1.

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Region	Kinesthetic Movements	Muscles Verbally Reviewed
Muscles of Respiration	Chest breathing, Abdominal breathing	Diaphragm, intercostal muscles (external, internal, innermost)
Core	Twisting, Lateral flexion	Obliques (external and internal), transversus abdominis, multifidus
Scapula	Elevation, Depression, Retraction, Protraction, Stabilization	Trapezius, rhomboid, serratus anterior, pectoralis minor, levator scapulae
Rotator cuff	External and internal rotation	Supraspinatus, infraspinatus, teres minor, subscapularis
Sternocleidomastoid	Lateral Flexion, Rotation	Sternocleidomastoid
Shoulders	Flexion, Extension, Abduction, Adduction	Deltoid (three parts), pectoralis major, latissimus dorsi, coracobrachialis
Elbows	Flexion with supination and pronation, Resisted flexion, Resisted extension	Biceps brachii, brachialis, brachioradialis, triceps
Wrists and Digits	Wrist flexion and extension, Digit flexion and extension	"Flexor compartment", "extensor compartment"
Spine	Flexion and extension in quadruped position ("Cat – Cow")	Rectus abdominis, erector spinae
Iliopsoas	Flexion, Stretch in Warrior I	Iliopsoas
Quadriceps	Knee Extension	Rectus femoris, vastus lateralis, vastus intermedius, vastus medialis
Hamstrings	Knee flexion, Stretch in laying position (Supta Padangusthasana)	Biceps femoris, semitendinosus, semimembranosus
Gluteal Muscles and Sartorius	External rotation in Warrior I	Gluteus maximus, gluteus medius, gluteus minimus, sartorius
Adductors	Wide leg standing	Adductor magnus, adductor longus, adductor brevis
External Rotators	Piriformis stretch	Piriformis, Superior and inferior gemellus, obturator internus and externus, quadratus femoris
Feet	Flexion and extension of feet and digits	Tibialis anterior, gastrocnemius, soleus, digital flexors, "digital extensors"
Savasana + Synthesis	Lie in anatomical position	Review

**Table 1:** Summary of the content of the kinesthetic review.

In the tactile experience, students were guided in shaping clay into models of muscles and placing them on a corresponding plastic skeleton, "Maniken" model ZSF-356 (Zahourek Systems Inc. and Affiliates, Loveland, CO). The instructor demonstrated creation of a specified muscle while discussing its proximal and distal attachments, as well as the actions of that muscle. Simultaneously, students began crafting their own clay versions of the same muscle, following along with the instructor. It was ultimately necessary that students worked in pairs due to the limited number (n = 18) of plastic skeleton models available. The session was

held in a small lecture classroom with standard tables and the instructor moved throughout the room for the duration of the session while demonstrating the modeling of the muscles and helping students pinpoint attachments for the muscles on the plastic skeleton. Students were provided with a worksheet to guide their notetaking about each muscle. Table 2 shows an outline of the guided notes for the clay modeling.

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Muscle(s)	Proximal Attachment	Distal Attachment
Erector Spinae	Inferior transverse processes of vertebrae	Superior transverse processes of vertebrae
Rotator Cuff (Supraspinatus, Infraspinatus, Teres minor Subscapularis)	Medial border of the scapula (superior to scapular spine, inferior to scapular spine, inferior to infraspinatus, anterior scapular surface)	Head of the humerus
Rhomboids	T2-T5 spinous processes	Medial border of the scapula
Teres Major	Inferior angle of the scapula	Proximal anterior humerus
Rectus Abdominis	Pubic symphysis	Xiphoid process and costal cartilage
Abdominal Obliques	Thoracolumbar fascia, inferior border of ribs	Iliac crest, inguinal ligament, linea semilunaris (continuing with aponeurosis to linea alba)
Latissimus Dorsi	Thoracolumbar fascia	Proximal anterior humerus
Trapezius	Nuchal ridge, C1-T12 spinous processes	Clavicle, acromion, and spine of the scapula
Gluteal Group	Posterior ilium, sacrum, and coccyx	Iliotibial tract and proximal posterior femur
Pectoralis Minor	Ribs 3-5	Coracoid process of the scapula
Pectoralis Major	Sternum	Proximal anterior humerus
Brachialis	Anterior distal humerus	Ulna
Coracobrachialis	Coracoid process	Proximal anterior humerus
Biceps Brachii	Coracoid process and supraglenoid tubercle of the scapula	Proximal radius
Triceps Brachii	Infraglenoid tubercle of scapula and posterior humerus	Olecranon process of the ulna
Deltoid	Clavicle, acromion, and spine of scapula	Lateral proximal humerus
Forearm Flexors	Medial epicondyle of humerus and anterior radius + ulna	Anterior wrist and digits
Forearm Extensors	Lateral epicondyle of humerus and posterior radius + ulna	Posterior wrist and digits
Iliopsoas	Anterior transverse processes of T12-L4, Iliac crest	Lesser trochanter of femur
Adductor Group	Ischiopubic ramus	Medial border of femur
Quadriceps Femoris	ASIS and anterior femur	Tibia via patellar ligament
Sartorius	ASIS	Superior medial tibia
Hamstring Group	Ischial tuberosity and posterior femur	Tibia and fibula
Deep Posterior Leg Muscle Group	Posterior tibia	Ankle and plantar surface of foot
Soleus	Tibia and fibula	Calcaneus via Achilles tendon
Gastrocnemius	Medial and lateral condyle of femur	Calcaneus via Achilles tendon
Anterior Leg Muscle Group	Anterior tibia	Ankle and dorsal surface of foot

**Table 2:** Summary of the guided notes page used during the tactile session.

The third review was an audience-response Q&A session in which students responded to questions digitally and received feedback about their performance. The Q&A session was held in the class lecture hall and consisted of a slideshow presentation created using Microsoft PowerPoint 2016 (version 16.0.4849.1000, Microsoft Corporation, Redmond, WA) with multiple-choice questions followed by slides with images of the relevant anatomy. Students were given time to read each question and select an answer independently using an audience-response remote polling system via their personal cellular devices (iClicker Cloud, formerly REEF,

Macmillan Learning, New York, NY). Following the allotted time, the correct answer was revealed and the number of students who selected each possible answer was shown on-screen. This gave both students and the instructor feedback as to how many people selected the correct or incorrect answers. The instructor then explained the correct answer and the incorrect answers, with more time given to explaining questions with a lower percentage of correct responses. The information assessed in the review is summarized in Table 3.

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Question	Correct Answer
Which of the following muscles causes flexion of the spine?	Rectus abdominis
Which of the following muscles causes lateral flexion of the spine?	Abdominal obliques and Erector spinae
Which of the following causes extension of the spine?	Erector spinae
Which of the following is an action of the latissimus dorsi?	Adduction at the shoulder
What is the proximal attachment of the teres major?	Scapula
Which of the following is <u>NOT</u> an action of the trapezius?	Protraction of the scapula
Which of the following muscles is responsible for abduction of the hip?	Gluteus maximus
Identify the indicated muscle(s)	Trapezius
Which of the following muscles does <u>NOT</u> attach to the skull?	Levator scapulae
Which of the following muscles attaches proximally to the humerus?	Brachioradialis
Which of the following muscle is responsible for flexion at the elbow?	Biceps brachii, brachialis, and brachioradialis
Which of the following is the proximal attachment of the hamstrings?	Ischium and femur
Which of the following muscles dorsiflexes the foot?	Gastrocnemius and soleus
Identify the indicated muscle(s)	Triceps brachii
Identify the indicated muscle(s)	Wrist extensors
Which of the following muscles is responsible for flexion at the shoulder?	Deltoid
What is the action of the sartorius muscle?	External rotation of the lower limb
What is the action of the rhomboids?	Retraction of the scapula
What is the proper order of muscles from superficial to deep?	Trapezius, rhomboids, and erector spinae
A 16 y/o African American girl presents to the emergency room with her parents. She had been competing in a gymnastic competition when she stuck a particularly challenging sideways landing, then collapsed. She points to her groin, saying that she felt a tearing there and it now hurts too much to walk. Which of the following muscle groups most likely related to this girl's pain?	Adductors
A 33 y/o Costa Rican man presents to a sports medicine clinic. He says that his right shoulder has been hurting him ever since his minor league baseball pitching career. He says that the pain is worse when he first lifts his arm, or when he tries to scratch his back. Which of the following muscle groups is most likely related to this man's pain?	Rotator cuff

**Table 3:** Summary of the question stems and the correct answers used for the multiple-choice Q&A review session.

These three review sessions were held simultaneously during the students' normal laboratory period. After each session, the same five-item quiz was given to students (referred to herein as the post-activity quiz). The quiz was developed by the session instructors in advance of the exercise, and the questions were targeted to the course skeletal muscle anatomy content that was emphasized in lecture. As the goal of the quiz was to capture any possible differences in foundational student knowledge, the questions were geared toward basic recall. Session attendance was assessed by totaling the number of completed quizzes.

Review effectiveness was assessed using the group mean score on the following three assessments: a post-activity quiz, overall performance on the following examination

which included questions muscle anatomy and other topics, and performance on only the muscle anatomy examination questions (referred to herein as examination muscle question sub-score). These data were compiled using Microsoft Excel (version 16.0.4849.1000, Microsoft Corporation, Redmond, WA). Statistical analysis and visualization was performed using GraphPad Prism software (version 8.1.0, GraphPad Software Inc., San Diego, CA). Differences between Q&A, tactile, and kinesthetic group performance on each assessment were analyzed using one-way analysis of variance (ANOVA). One-way ANOVA was chosen because of the data set consisting of three sets of discrete values (for example, post-activity quiz scores for the Q&A group, the kinesthetic group, and the tactile group were compared). Differences were considered statistically significant if  $p < 0.05$ .

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This study was approved with exempt status by the University of Kentucky Institutional Review Board (IRB) on account of being limited to traditional classroom activities with minimal risk for participants, Protocol No. 16-0796-X1B, titled "Self-selected kinesthetic, tactile, or question-based learning modalities and their impact on examination performance." Only students who signed informed consent documentation ( $n = 345$ ) were included in this study. The remainder of the students enrolled in the course ( $n=100$ ) were still required to participate in the multimodal session of their choice, as it was serving as one of their laboratory sessions, but were excluded from any data collection or subsequent analysis. Students who did not participate in any session lost the points associated with the weekly laboratory assignment (fifteen points out of 497 possible for the course; 3% of course grade). Study personnel (A.W., L.W., and K.P.) were trained in human subject protection per University of Kentucky Office of Research Integrity protocols.

## Results

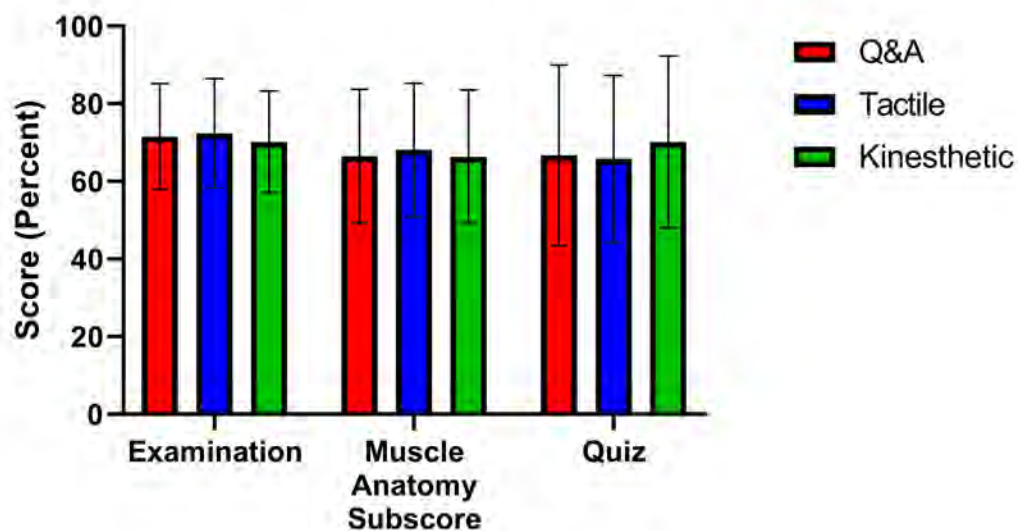
### Participation

A total of 345 students consented to and participated in the study. Session participation was as follows: Q&A  $n = 180$  (52.2%), Tactile  $n = 99$  (28.7%), and Kinesthetic  $n = 66$  (19.1%). This total number of participants was divided over three laboratory sections, each allotted up to one hour and fifty minutes, less time for the quiz. Total attendance at each session ranged from 81-93 per Q&A session, 39-40 per tactile session, and 25-35 per kinesthetic session.

The overall reliability of the quiz as a testing instrument was extrapolated by averaging the Kuder-Richardson (KR) Reliability Index for the three output groups. The KR for the quiz based on this approach is 0.19. The KR for the instrument group by group is: 0.26 for the Q&A group, 0.09 for the tactile clay group, and 0.21 for the kinesthetic group. Interestingly, the Discrimination Index (DI) for each of the quiz questions varied by group. In brief, the DI for question 1 was highest in the Q&A group and lowest in the Kinesthetic group, the DI for question 4 was consistently very high across the groups, middling for question 5, and variable for questions 2 and 3.

### Assessment Performance

There was no significant difference in student performance on any of the three assessments (total examination score ( $p=0.59$ ), examination muscle question subscore ( $p=0.15$ ), or post-activity quiz score ( $p=0.46$ )) as assessed by one-way ANOVA. Figure 1 summarizes these results. The examination scores were  $71.6\% \pm 13.6\%$  for Q&A,  $72.4\% \pm 14.1\%$  for the tactile group, and  $70.1\% \pm 13.1\%$  for the kinesthetic group ( $F = 0.33$ ,  $p=0.59$ ). For the post-activity quiz score, performance out of 5 points possible was 3.3 (Q&A group), 3.3 (tactile group), and 3.5 (kinesthetic group) ( $F=0.78$ ,  $p=0.46$ ). Similarly, examination muscle question sub-score did not significantly vary between groups ( $65.4\% \pm 18.3\%$  for the Q&A group,  $67.7\% \pm 18.3\%$  for the tactile group, and  $66.7\% \pm 17.1\%$  for the kinesthetic group;  $F=0.33$ ,  $p=0.72$ ).



**Figure 1:** Comparison of total examination scores, examination muscle question subscores, and post-activity quiz scores based on review session attended (Q&A, Tactile or Kinesthetic).

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## Discussion

This pilot study was successful in developing and implementing three different review sessions, each designed to engage a different sensory modality for learning muscle anatomy. Details for each section are discussed in the Implementation Feasibility section below. As a research study this work had several significant limitations, namely student self-selection and the lack of a pre-test. These factors are discussed in further detail in the Limitations section. In light of these limitations the study cannot draw firm conclusions from the performance data as to the efficacy of these sessions.

The authors are of the opinion that presenting information in multiple modalities to all students is generally the best educational approach. Due to the limitations of implementing this study during the scheduled course hours, it was not feasible to allow students to attend multiple review sessions. Nonetheless, it would be of great interest to the authors to study how providing multiple review sessions using different modalities to address the same content topic would affect student learning outcomes. Likewise, the simultaneous delivery of information through multiple modalities is also of interest. The principle of dual coding, which is widely accepted in educational literature (Pashler et al. 2008), predicts that all learners should benefit if visual information is layered over linguistic information. Does this principle hold true for the simultaneous delivery of kinesthetic and linguistic information, tactile and visual information, or even combinations of more than two modalities for learning appropriate subjects? Answering these questions may inform future evidence-based curriculum design.

This study asked students to indicate their preferred review session, each structured around a different learning modality. However, this study did not address student's generally preferred learning style. Well-controlled studies looking at student learning style preferences have failed to show that a student's preferred learning style is more effective for promoting learning in that student, independent of subject (Constantinidou and Baker 2002; Cook 2012; Cuevas and Dawson 2017; Husmann and O'Loughlin 2019; Knoll et al. 2017; Krätzig and Arbuthnott 2006; Massa and Mayer 2006; Rogowsky et al. 2015). In fact, various studies now directly question the actual impact, importance, and effect of targeting learning styles as a means to enhance student outcomes (Cook, 2012; Husmann and O'Loughlin 2019). For a complete review, see (Cuevas 2015; Pashler et al. 2008). Instead, perhaps certain subjects are better suited to incorporating different learning styles into their teaching and learning methodology. This study suggests that while not all subjects can cater to preferred learning approaches, anatomy is an appropriate subject for developing kinesthetic and tactile learning curricula.

## Implementation Feasibility

This study was executed during a typical undergraduate course, demonstrating the feasibility of implementing these educational sessions with appropriate resources and support, even for large numbers. These review sessions were conducted without cadavers, ultrasound machines, or specialized digital tools that other anatomy education approaches may require (Estai and Bunt 2016; Griksaitis et al. 2012). While the above tools offer great value for anatomy education, they are not always available, the local budget may not allow their application, nor are they always conducive to use in large groups. The large number of students enrolled in the course (445, including students who did not consent to participate in the study), did make it a challenge to create interactive sessions that could accommodate all participants. Smaller groups would allow more individual attention for students and would alleviate many space and resource constraints. Also of note, nearly half ( $n=165$ , 47.8%) of the study participants preferred to attend a tactile or kinesthetic review session to an audience-response Q&A review of muscle anatomy when given the choice. This desire for alternate learning environments highlights the demand for multimodal anatomy curricula, especially with evidence that alternative modalities are effective in communicating anatomy information.

The kinesthetic session, while novel and exciting, posed a number of challenges. A vital consideration for holding an institution-approved kinesthetic session was taking proper safety precautions. L.W., the author who led the kinesthetic sessions, is a licensed and insured yoga instructor with experience leading groups with a spectrum of physical fitness levels from young, fit individuals to less active, elderly individuals. Space considerations include a room large enough to hold all participants, ideally somewhat private, with access to mats or other surfaces for standing, sitting, and laying down.

For the tactile session utilizing clay modeling on plastic skeletons, instructors considering using a similar approach must be aware of the resource burden and space requirements. For example, funds must be secured to purchase the modeling clay and skeletons. If the instructor only has access to a few skeletal models, then this limits the number of students who can learn from the approach by a truly tactile method. Some students also may not prefer to handle the clay and, without appropriate work mats and student care for tidiness, soiling of the classroom surfaces is possible.

The Q&A session is the most traditional review session in this study. Audience-response systems are common in higher education (Alexander et al. 2009; Mareno et al. 2010) and the Q&A session used multiple-choice questions similar to those used for their examinations. When this study was conducted, all students in the course were required to purchase the

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iClicker Cloud audience-response application for their personal cellular devices (Macmillan Learning, New York, NY) for this course as well as for other courses in the pre-nursing curriculum. Current technologies such as TurningPoint Web (Turning Technologies, LLC, Youngstown, OH) and Poll Everywhere (Poll Everywhere, San Francisco, CA) are similar options that allow for audience-response using only smartphones or laptops. Both of these examples use a paid subscription model but offer additional options for real-time instructor feedback during Q&A sessions. There are additional free options that exist, as well, and many of them “gamify” the interaction, granting points for correct and speedy answers. One advantage of web-based polling technologies is that they do not require a remote receiver to be installed in the instructor’s computer. Whatever the tool, audience-response technology empowers instructors with real-time feedback on student comprehension and engages students with an interactive educational activity.

### *Study limitations*

There are limitations of this study with regards to measuring the absolute effect of each review session on student learning. First, it is possible that the muscle anatomy knowledge of students differed between groups before the review sessions, and that each review session had different effectiveness that brought their average performance to be equivalent on the post-review quiz and examination. Second, it is possible that all review sessions had a small effect on muscle anatomy knowledge that could not be measured with the post-activity quiz or muscle anatomy questions on the examination (referred to here as examination muscle question subscore). Both of these possibilities could be assessed in future work using a pre-test / post-test methodology in which students were given an assessment before the review session to compare their anatomy knowledge before and after the reviews.

This study is limited by lack of control in the form of pre-review session knowledge of muscle anatomy between groups. Without a pre-test assessing muscle anatomy knowledge prior to the review sessions this study cannot conclusively show that muscle anatomy knowledge was equivalent between different review sessions prior to the session. A follow-up study would incorporate a pre-test methodology to ascertain the study population’s muscle anatomy knowledge prior to the interventions. In addition, it would be of interest to test the student participants with a quiz focusing on higher-order questions per Bloom’s Taxonomy. While the current work found no differences in performance on basic recall-level questions, perhaps the alternate modalities would reinforce higher-order knowledge differentially.

In addition, because students self-selected their review session modality, there is potential for selection bias in the pre-review session knowledge of muscle anatomy. It is possible that student performance may not have

been equal if students were randomly assigned to a review other than their preferred session. The authors do note that the intention of this research is to investigate alternative methods of education that may be more effective for students based on increased engagement. If students were randomly assigned to a review other than their preferred session then the majority would not be placed in their preferred session, and this may have led to decreased student engagement. The authors considered a follow-up study in which the review session groups were assigned instead of self-selected but have not yet pursued such project. An appropriate study design would directly investigate this effect by randomizing part of the cohort while allowing the remainder of students to choose their session and comparing student performance and markers of engagement.

Finally, the current study has no means to measure the qualitative value, or lack thereof, regarding the multimodal approaches. As anatomy is a topic that is very physical and universal in its nature, since all humans have a human body, exploring it through various interactive means seems logical. The intrinsic value of these alternate approaches may be more abstract and, therefore, difficult to measure through basic recall. Future studies would do well to include qualitative measures of student learning, growth, and engagement to explore these possible markers of the approaches’ value.

### **Conclusion**

This study explored multimodal methods for teaching muscle anatomy by developing and implementing three review sessions: a question-and-answer review using audience-response technology, a tactile review using clay modeling, and a kinesthetic review using guided movement sequenced similar to yoga. Materials used in these review sessions are provided so that they may be adapted by anatomy educators for their own needs. The authors encourage educators to use these and other educational approaches in combination, as engaging multiple learning modalities is beneficial for all students.

### **About the Authors**

Andrew Welleford is an MD-PhD student at the University of Kentucky College of Medicine. His research interests include medical sciences education and neurodegenerative disease.

Lauren Weaver, B.S. is a certified Geographic Information Systems Professional and master’s student in Information Communication Technology. She seeks to help others acquire an understanding of their own minds and bodies.

Kristen Platt is an assistant professor in the Department of Neuroscience at the University of Kentucky College of Medicine. Her scholarship interests are the areas of education best practices and the medical humanities.

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