REIGNITING THE LOVE OF LEARNING: PHYSICAL AND INTERACTIVE METHODS IN LIFE SCIENCE EDUCATION

A Dissertation

by

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ABSTRACT

A foundational understanding of basic concepts in the life sciences is crucial to the success of pre-professional and professional health-care students. Educational theories such as the Zone of Proximal Development, Cognitive Load Theory, Experiential Learning Theory, and Constructivism can help instructors to design and implement tools that are more effective in supporting student learning of these crucial concepts. These theories also bring light to issues with current instructional tools including a lack of dynamic, tactile, or interactive elements. In an attempt to resolve these issues with tools which address solutions proposed in educational psychology, a physically interactive model was designed and constructed. This model included components which demonstrate concepts across different life-science disciplines including gross anatomy, histology, physiology, and kinesiology. A study of the effect and influence of the model was conducted in a large undergraduate Biomedical Anatomy course and compared to various other instructional methods. Results showed that students in all groups (control, activity control and intervention) experienced changes in attitudes, motivations and study methods throughout the study – most of which were positive changes. All students made significant improvements between preliminary and post quizzes, however the improvement for both the control group and the intervention group were significantly higher than the activity control group for two topics assessed. Considering the consistently higher performance of the control group and consistently lower performance of the intervention group, the improvements in quiz scores for the intervention group could be attributed to interaction with the model, although further study is required. In addition, qualitative results showed that students perceived interaction with the model as both enjoyable and beneficial to their learning.

DEDICATION

To my mom and my bonus mom, two of the most incredibly strong and influential women I know. We got it done!

I love you.

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I would like to thank my mom, Denise Collier, for supporting me in every way she could including helping me to grade spatial assessments and input data.

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Contributors

This work was supervised by a dissertation committee consisting of Dr. Michelle Pine [advisor], and Dr. Cheryl Herman of the Department of Veterinary Integrative Biosciences, Dr. Diane Chico of the College of Medicine, Department of Neuroscience and Experimental Therapeutics, Dr. Jinsil Hwaryoung Seo of the College of Architecture, Department of Visualization, and Dr. Ra'sheedah Richardson, Assistant Director for the Center for Teaching Excellence [special appointment].

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NOMENCLATURE

ZPD	Zone of Proximal Development
CLT	Cognitive Load Theory
ELT	Experiential Learning Theory
3D	Three-Dimensional
2D	Two-Dimensional
CT	Computed Tomography
MRI	Magnetic Resonance Imaging
ACh	Acetylcholine
UGTA	Undergraduate Teaching Assistant
PMRT-R	Revised Purdue Spatial Visualization Tests: Visualization of Rotations
ASRA	Anatomic Spatial Reasoning Assessment
GPA	Grade Point Average
BIMS	Biomedical Sciences
VIBS	Veterinary Integrative Biosciences
VTPP	Veterinary Physiology and Pharmacology

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1 INTRODUCTION

Research shows that a foundational understanding of basic life sciences is crucial to success in any professional health-science curriculum (Hadie et al, 2017; Hu et al, 2017; Smith & Mathias, 2010; Wilhelmsson et al, 2010). Without it, professional students are overwhelmed by the expectation to apply concepts to new structures and clinical situations (Karaer & Barut, 2017; Wilhelmsson et al, 2010). For this reason, it is crucial that students master basic life science curricula beyond the level of rote memorization prior to attending professional school (Karaer & Barut, 2017; Wilhelmsson et al, 2010).

To facilitate the establishment of this foundational understanding, teaching life sciences is largely reliant on visual aids such as diagrams, illustrations, cadavers, microscopic images, and static physical models. Diagrams, illustrations and static models help provide clarity to students struggling to identify structures and provide a framework for the spatial organization of the structures relative to one another (Collins, 2008). In gross anatomy, cadaver dissection and prosections help immensely with students' ability to relate structures to one another and understand the gross composition of tissue. In histology and cell biology, histological slides and electron micrographs provide accurate and comprehensive illustrations of the cellular composition of tissues. In other life science courses such as biochemistry or physiology, diagrams and illustrations simplify concepts by providing an idealized representation of what components of different mechanisms look like and how they interact (Goodsell & Jenkinson, 2018). These tools may aid students in creating mental models used as reference when mastering concepts in life science, but when asked to apply these mental models to tasks beyond structure identification and describing basic functions, it becomes clear that most students are unable to integrate and apply information using these models alone (Goodsell & Jenkinson, 2018;

Jittivadhna, Puenwongsa & Panijpan, 2009; Oh et al 2009; Wilhelmsson et al, 2010). Further, there is a paucity of illustrative tools that successfully demonstrate abstract, three-dimensional (3D), and dynamic concepts such as biomechanics and the architecture of skeletal muscle. The challenges associated with the students' ability to gain the appropriate level of mastery of some of the critical topics in microscopic and gross anatomy might be overcome with the use of additional or modified instructional aides (Hu et al, 2017; Jittivadhna, Puenwongsa & Panijpan, 2009; Wilhelmsson et al, 2010). One such modification to the existing physical models would be to incorporate motion to illustrate dynamic functions and introduce elements of interaction to promote active, engaged learning (Greene, 2018; Hu et al, 2017; Jittivadhna, Puenwongsa & Panijpan, 2009; Karaer & Barut, 2017; Lisk et al, 2014; Mcculloch, 2010; Oh et al 2009; Peeler et al, 2018; Royer et al, 2016; Wilhelmsson et al, 2010).

1.1 Theories in Educational Psychology and Current Instructional Tools in Life Science Education

In order to appropriately design tools to more effectively demonstrate abstract, 3D and dynamic concepts, one must first consider current instructional tools and their adherence to well-researched theories in educational psychology. In this way, those aspects of current tools which are effective can be optimized and those which are not can be replaced or eliminated.

1.1.1 Vygotsky's Zone of Proximal Development

In many cases, mastery of life-science concepts requires cognitive processes which draw upon previous knowledge and requires support and mentoring to fully understand. These cognitive processes fall within what Vygotsky (1977) defined as the students' zone of proximal development (ZPD) (Darling-Hammond and Bransford, 2005; Vygotsky, 1977).

Within the zone of proximal development, students are asked to complete a task which they cannot accomplish independently, but that they could complete with limited support, thus stimulating cognitive development (Berk and Winsler, 1995; Darling-Hammond and Bransford, 2005; Vygotsky, 1977). Essentially, a student's ZPD is the gap that exists between what they are able to learn on their own without any aid and the learning that they would be able to attain with some sort of assistance (Murphy, Scantlebury and Milne, 2015). Vygotsky termed the support and assistance required to fill this gap "scaffolding" (Darling-Hammond and Bransford, 2005; Murphy, Scantlebury and Milne, 2015).

Specifically, within science teaching, ZPD has been celebrated for its potential to support the development of innovative activities while addressing interactions among peers, instructors, and instructional tools (Murphy, Scantlebury and Milne, 2015). It is likely that textbooks, guides, illustrations, and diagrams can provide appropriate scaffolding for the smaller "gaps" present when teaching less abstract concepts such as would be introduced in lower-level life science courses. However, as concepts become more abstract and grow in complexity, as is expected in upper-level life science courses, the scaffolding tools that are used should also evolve as they are being used to bridge larger "gaps" in student learning.

1.1.2 Cognitive Load Theory

Cognitive load theory (CLT) is a theory developed specifically for instructional design. The tenets of CLT are based on the intricate architecture of human cognition as they are relevant to instructional tools and their success or failure in the learning environment (Sweller, Ayres and Kalyuga, 2011). When evaluating instructional tools, the efficiency in the tool's design is often only evaluated by the overall cognitive load that it imparts on learners. In other words, the instructional tool is considered wholly effective if it presents information that fits nicely into a learner's limited working memory and wholly ineffective if it does not. Instead, CLT considers that a learner's limited working memory for novel tasks is affected by several defined factors which should all be considered when evaluating instructional tools:

1. *Intrinsic load:* the load that is imposed by the information that the learner needs to acquire considering the learner's previous knowledge and the complexity of the task regardless of instructional aid.
2. *Extraneous load:* the load created by the presentation of instructional materials and any superfluous processes that do not directly contribute to learning.
3. *Germane load:* the learning processes involved in constructing knowledge regardless of the nature or structure of the learning materials (Lisk, et al, 2014; van Merrienboer and Sweller, 2010; Sweller, Ayres and Kalyuga, 2011).

Effective instructional tools should manage intrinsic load with thoughtful presentation of what is learned, decrease extraneous load so that the total cognitive load is not greater than a learner's working memory, and act according to the germane load of learners (Sweller, Ayres and Kalyuga, 2011).

As the intrinsic load of life-science materials increases, instructors must be careful not to increase the extraneous load by providing tools which are incomplete in their presentation of the material. Tools such as fixed tissues, illustrations and static physical models are efficient when learning identification and basic structural organization. However, when a student is asked to understand and apply concepts related to functions that are inherently dynamic and three-dimensional, these tools begin to lose their efficiency (Bentley and Pang, 2012; Jittivadhna, Ruenwongsa and Panijpan, 2009; Lisk et al, 2015). They are no longer working to support the intrinsic load and, in many cases, increase the extraneous load for learners with significantly higher germane loads. Some learners may have higher germane loads due to spatial or temporal challenges (referred to as split-attention in CLT) (Canty et al, 2015; Goodsell & Jenkinson, 2018; Jittivadhna, Puenwongsa & Panijpan, 2009; Oh et al 2009;Sweller, Ayres and Kalyuga, 2011; Wilhelmsson et al, 2010).

In order to address this limitation, instructional tools such as videos, three-dimensional computer graphics, and computer-based interactive modules have been developed. These tools have yielded mixed results (Hoyek et al, 2014). Much of this can be attributed to the challenges presented to learners with higher germane loads caused by spatial and temporal factors. The following limitations were recognized when evaluating the efficiency of these tools:

1. Inability to manage intrinsic load by overlooking problems involved in creating mental models for functional anatomy (such as movement or spatial reference),
2. Increased extraneous load by demanding a prerequisite level of spatial ability that struggling students are not likely to possess, or
3. Increase in germane load because of low to nonexistent levels of student engagement and interaction (Berney et al, 2015; Canty et al, 2015; Hoyek et al, 2014; Jittivadhna, Ruenwongsa and Panijpan, 2009; Lisk et al, 2015; Nguyen, Nelson and Wilson, 2012).

1.1.3 Experiential Learning Theory

The use of instructional tools which involve student interaction and engagement is further supported by David Kolb's (1984) experiential learning theory (ELT). This theory states that learning is a process rooted in participation and direct experiences. However, Kolb is careful to indicate that not all experiences are meaningful or relevant. If, however, an experience can be made to directly relate and create meaning within a certain learning task, mindset can be linked to realities and the students' involvement in learning can be enhanced (Chiu, 2019; Kuk and Holst, 2018). Within ELT, David Kolb proposes a learning cycle with four stages (Figure 1):

- Concrete Experience: the time during which students are allowed to directly experience the concepts being learned.
- Reflective Observation: the time allowed for students to visually observe and reflect upon their experiences.
- Abstract Conceptualization: the time during which students are allowed to create mental models of abstract ideas by applying the knowledge that they have acquired to justify and explain their experience.
- Active Experimentation: the time allowed for students to make use of and refine the knowledge they have gained by conducting their own experiments. (Bentley and Pang, 2012; Chiu, 2019; Kolb, 1984; Kuk and Holst, 2018; Lisk et al, 2015).

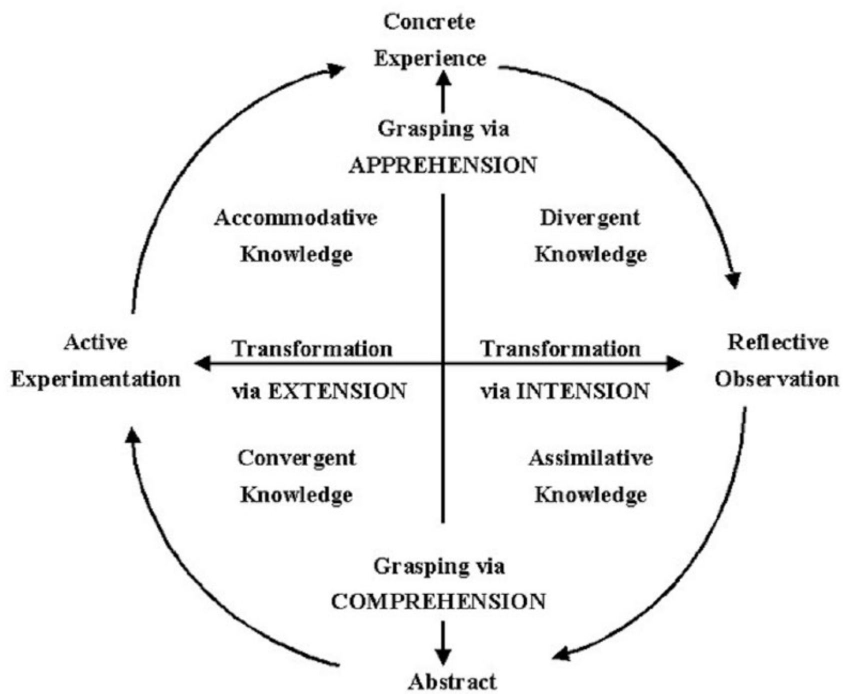

Figure 1: Kolb's learning cycle model of experiential learning (Kolb, 1984)

While ELT's core tenet is experience, it is important to first assure that the experience is relevant to the learning task and, second, is followed by meaningful reflection to mediate between experience and learning (Kuk and Holst, 2018). Laboratories that accompany traditional presentation of life-science material are particularly suited to maximizing the use of ELT. However, if students are not able to recognize the relevance of their experience in the laboratory, it only creates an entirely new learning task that students will take on independently of other information (Brevik, 2019). This both increases the students' load and leads to misconceptions and confusion which are often only realized during formal, high-stakes assessments.

1.1.4 Constructivism Theory

The constructivism theory, which is closely related to ELT, also supports the use of physically interactive tools to aid in learning. In constructivism, learning is defined as a selfregulatory process that involves struggling through the discrepancies created by existing models and new insights. The theory rejects the idea that meaning and understandings of whole concepts can be broken down into discrete parts and passed to learners. It also rejects the idea that learners should have, and use, an exact copy of the teacher's understanding. The theory instead suggests that learners are given the opportunity to create concrete, contextual and meaningful experiences so that they are allowed to search for patterns, ask questions, and eventually defend their own understanding (Fosnot, 2005; Jonassen and Ronrer-Murphy, 1999; Mione, Valcke and Cornelissen, 2016).

The intricate visual and spatial elements involved in many of the more difficult concepts in life science emphasize the importance of allowing the student to take on a role as an active participant in the learning environment (Jonassen and Ronrer-Murphy, 1999; Mione, Valcke and Cornelissen, 2016; Winterbottom, 2017). Students have differing experiences, ideas, understandings, learning styles, and communication styles which should be accommodated by providing opportunities that allow students to construct their own understand in the way that makes the most sense for them (Alexandra & Georgeta, 2011). Interactive tools that encourage students to experiment and demonstrate understanding is one way to make that opportunity available to a large number of students (Fostnot, 2005).

1.2 Refining Tools to Better Fit Students' Needs

Scaffolding to effectively bridge the ZPD, or gap, when learning life-science concepts which impart significant cognitive load on students should promote construction of knowledge through meaningful experimentation and reflection. Instructional tools which facilitate student engagement, interaction, and active participation could provide this type of scaffolding and yield more positive results than current methods in many areas of life-science education (Berney et al, 2015; Hoyek et al, 2014; Jittivadhna, Ruenwongsa and Panijpan, 2009; Lisk et al, 2015; Mione, Valcke and Cornelissen, 2016).

Studies of both virtual and physical instructional tools designed with a focus on the elements of student engagement, interaction and active participation found that students:

- preferred the more interactive tools over traditional tools,
- retained information longer when using interactive tools,
- found information presented with interactive tools more interesting than the same information presented with other instructional tools or methods, and
- applied and experimented with previous knowledge when using interactive tools (Berney et al, 2015; Hoyek et al, 2014; Jittivadhna, Ruenwongsa and Panijpan, 2009; Lazarus et al, 2014; Lisk et al, 2015; Mione, Valcke and Cornelissen, 2016).

In response to the need for an appropriate scaffolding tool to promote learning in the life-sciences with the essential elements mentioned in the educational theories discussed, a physically interactive model and accompanying activities were created. This model, and its accompanying activities, represent concepts across many different life-science disciplines including gross anatomy, histology, physiology, & kinesiology. The model was used in a large undergraduate Biomedical Anatomy course and compared to other instructional methods.

2 MATERIALS AND METHODS

2.1 Intervention Model Construction

2.1.1 Methodology Influencing Model Design

For this study, the model will demonstrate concepts related to gross anatomy, histology and physiology including basic biomechanics, skeletal muscle histology and physiology and the peripheral nervous system. The model is made from easily accessible and reproducible materials and the basic method for making the model interactive is easily transferable to other topics. Further, the model can be used for individual or group study and the activities designed to facilitate interaction with the model can be completed during a normal laboratory period without detracting significantly from time spent on other activities. For this reason, this model, or a similar model designed with the same objectives, could be used in undergraduate life-science classes anywhere in the world regardless of class size. Professional and graduate gross and micro anatomy courses could also benefit from a model such as the one designed for this project to illustrate advanced concepts and clinical applications.

Due to the heterogeneity of students preparing for careers in either human or animal medicine, the model for this study required relevant representations of both human and animal anatomy. Canine cadavers are dissected and used as a pattern animal in the undergraduate biomedical anatomy course used for this study. Static illustrations and models of human anatomy are used as supplements. Therefore, a canine limb was used for representations of animal anatomy alongside the analogous limb from a human. Components of the model representing skeletal muscle architecture and physiology or portions of the nervous system were not specific to any species. In addition to providing an interactive and accurate instructional tool, it was determined that the model should meet three basic requirements:

- adhere to the principles of experiential learning in constructivism
- be physically durable & stable
- be aesthetically pleasing & anatomically accurate

Previously, bones for kinetic simulation models have been created using a molding and casting technique. These models were durable and accurate as they were made from actual bones (Malone et al, 2019; Malone et al, 2017; Malone, Pine & Bingham, 2016). Limitations of this method however include the significant weight of the simulated bones and the difficulty of creating any holes or connection points without compromising the stability to the structure. In addition, bones had to be molded and cast individually, then re-articulated so that sufficient definition between smaller bones (i.e. the carpal bones) could be created.

Recently, 3D printing has proven to be a valuable tool in anatomy education from undergraduate education through preoperative planning (Garas et al, 2018; Lim et al, 2015; Mogali et al, 2018; Ploch, et al, 2016; Smith et al, 2017; Vakharia, Vakharia & Hill, 2016; Wu, et al, 2018; Yi, et al, 2019). The cost of 3D printing accurate models is also relatively low (Mogali et al, 2018; Li et al, 2017; Lim et al, 2015; Shen et al, 2018). In addition, even when using computed tomography (CT) scan images, models can be modified to enhance the quality or alter the structure of the 3D printed object (Shen, et al, 2018). Finally, 3D printed models have been shown to be lighter and more durable than other physical instructional aides (Mogali et al, 2018; Li et al, 2017; Lim et al, 2015; Smith et al, 2017). Due to the advantages of 3D printed models, most of the components of the current model are created using 3D modeling software and an Ultimaker 2+ 3D printer. Basic models of the human and canine skeleton were purchased and a trained 3D modeling artist, who is also an anatomist, refined details and added built-in articulations and connection points for simulated muscles (Figure 15). All other 3D printed portions of the current model (that is, any part that is not skeletal structure), were completely designed and modeled by the same 3D modeling artist. Models were altered or created using Autodesk Maya ® 2019, exported as an .obj or .stl file, and imported into Ultimaker Cura. Within Ultimaker Cura, models were sized and checked for printability. This software also provided the opportunity to customize supports, thickness of the print and several other details associated with how the printed model is created. Once the model was ready to be printed, it was saved onto an SD Card as a .gcode file and sent to the Ultimaker 2+ 3D printer (Figure 2).

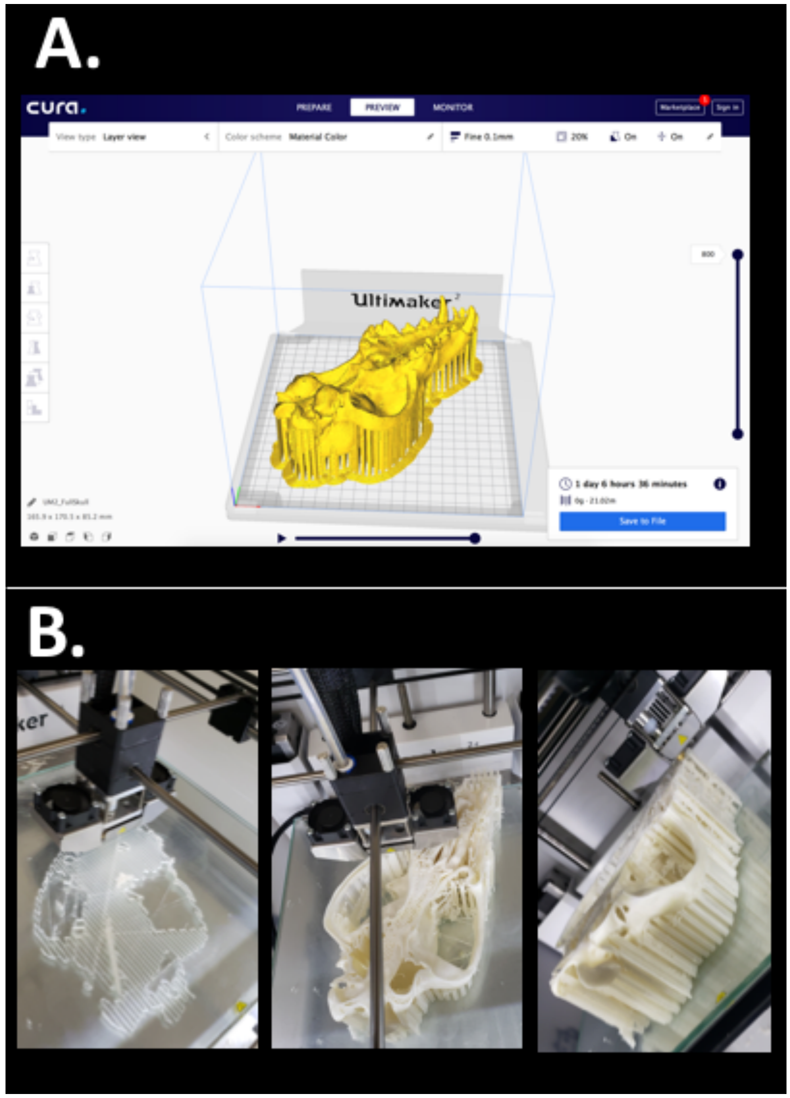

Figure 2: Example of 3D printing process using a canine skull model, A. Preparing a model to print in Ultimaker Cura, B. 3D model being printed in layers with supports on print plate

2.1.2 Structural Support

For this study, students interacted with the model in the gross anatomy laboratory. For this reason, it was important that the stand and base for the model did not absorb any chemical odors, was easy to clean, provided sufficient stability, and provided enough space for interaction. Considering that the model would be used in the gross anatomy laboratory alongside many different chemicals, it was important that the stand was not able to absorb and emit the odor from these chemicals. The flat base of the stand is made of a wooden board which is 48 inches long, 24 inches wide and 2 inches tall. One large 24 inch (length) by 2 inch (width) by 24 inch (height) wooden board stands vertically on the back of the larger base. On either side of the large vertical stand is a 3.5 inch by 3 inch by 36 inch wooden stand for the canine and human limbs. To attach the limbs and allow for sufficient movement, a 1.5 inch by 8 inch by 3.5 inch wooden block was attached to the top of the tall stand on the right of the model for the canine limb, and a 1.5 inch by 12 inch by 3.5 inch wooden block was attached to the top of the tall stand on the left of the model for the human limb (Figures 3 and 4). All the wooden parts of this stand and base were painted with an oil-based paint to protect from it from chemicals and moisture.

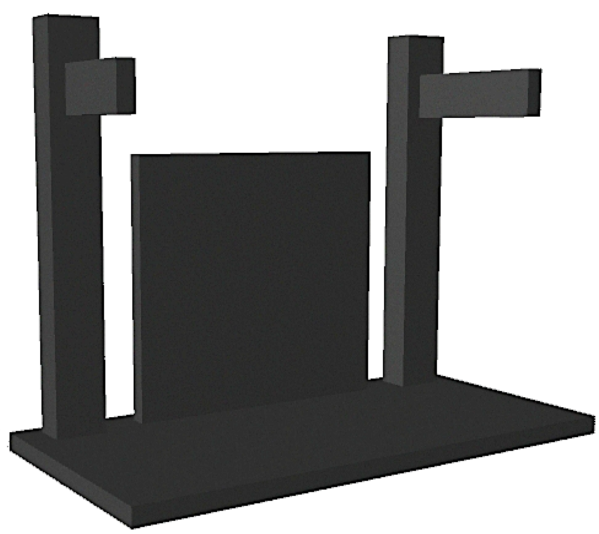

Figure 3: 3D modeling software rendering of model stand

Figure 4: Actual model stand after full construction and assembly

2.1.3 Structure for Thoracic Limb Myology and Basic Biomechanical Concept Illustration

When creating bones to represent biomechanical concepts, four primary requirements for simulated bones were identified:

- Light enough to allow for easy manipulation
- Durable and stable in articulation
- Accurate representations of major attachment points and range of motion
- Easily repaired or reproducible

The current model was not intended for teaching or learning the detailed anatomy of individual bones. Rather, only the overall bones and major attachments points (i.e. tuber olecrani of the ulna, greater tubercle of the humerus) had to be recognizable. For this reason, there was no need for the kind of accuracy that could be created with CT scans or MRI data. Instead, basic models of a human and canine skeleton were purchased from TurboSquid.com. To create free-standing limbs that would also demonstrate movement when muscles contract, (simulated by pulling strings), a trained 3D modeling artist and anatomist altered the purchased models to include articulating components of joints and refined details of attachment sites and holes for the simulated muscles to attach to or pass through.

2.1.3.1 Joint Articulation

For this model, the specific structures associated with the articulation of joints did not need to be represented with complete accuracy. It was more important that the limbs were free-standing and would represent relatively accurate ranges of motion. After assembly, all articulating surfaces were treated with a plastic lubricant to act as synovial fluid and articular cartilage, allowing smooth movement of the joints and protecting the surfaces from damage.

2.1.3.1.1 Humeral (Shoulder) Joints

- *Canine*: A customized notch and groove joint was created so that the primary motions were limited to the sagittal plane (flexion and extension). Very slight abduction and adduction capabilities were accounted for by making the groove on the articulating portion of the scapula slightly wider than the notch attached to the articulating portion of the humerus. Very thin portions of 3D printed models tend to be significantly more fragile. The thinnest portion of the customized notch and groove joint was, therefore, reinforced with aluminum rods and epoxy (Figure 5).

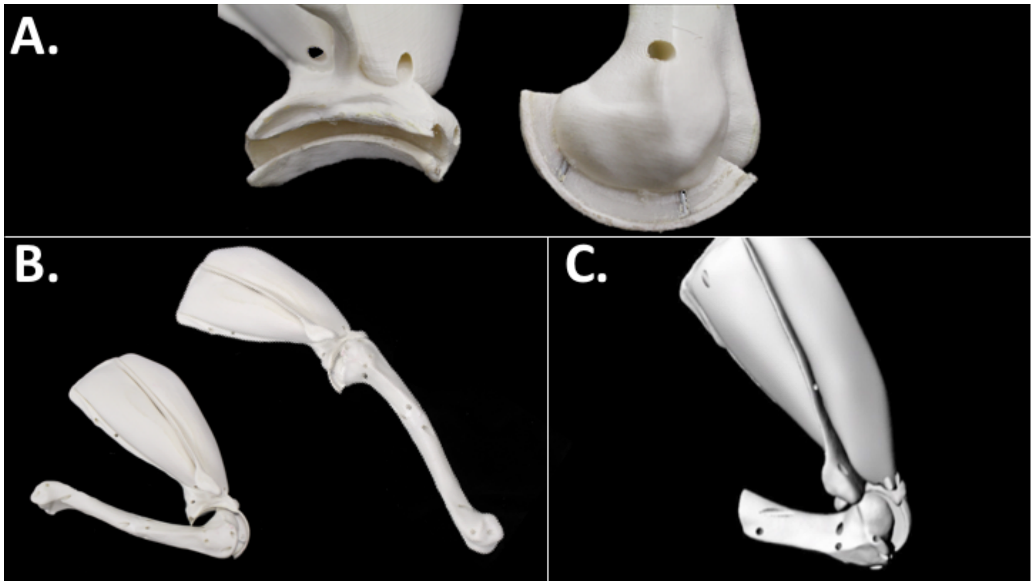

Figure 5: Canine humeral (shoulder) joint, A. Disarticulated distal (end) scapula and proximal (top) humerus demonstrating customized notch and groove joint, B. Articulated joint demonstrating range of motion in the sagittal plane (flexion – left and extension – right), C. 3D animation software rendering of articulated joint in flexion

- *Human*: A self-stabilizing ball-and-socket joint was built into the human shoulder joint by extending a sphere a short way from the articulation point on the humerus (head of the humerus) and inserting a concealed socket into the articulating surface of the scapula (glenoid cavity) (Figure 6). Although this simulated joint does not represent a normal full range of motion for the human shoulder, it was determined that it did sufficiently represent the primary motions of the shoulder (flexion, extension, abduction, adduction, internal & external rotation).

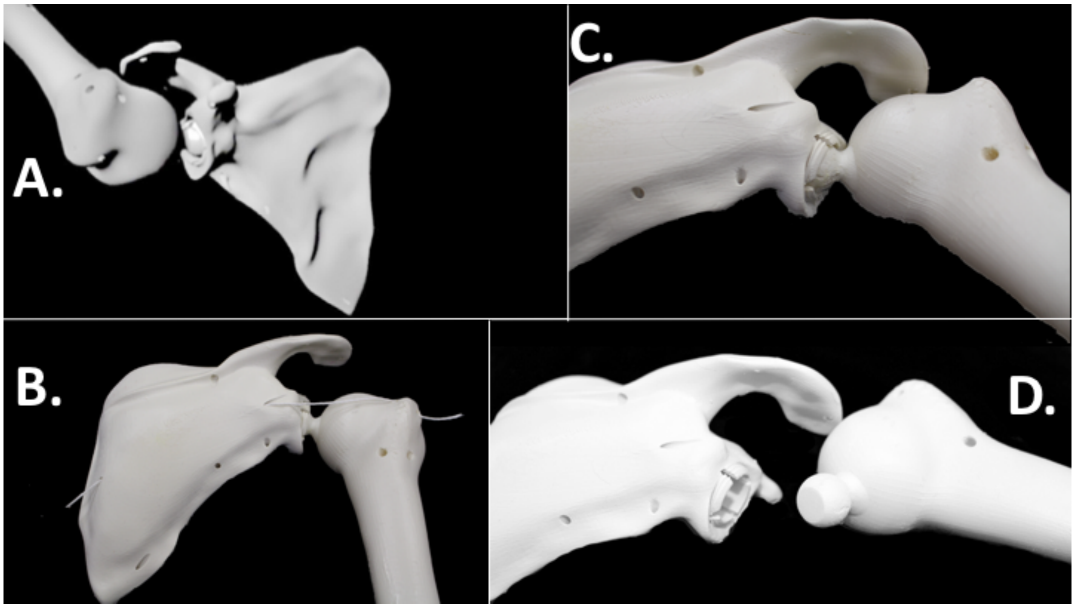

Figure 6: Human humeral (shoulder) joint, A. 3D animation software rendering of articulated joint in extension, B. Articulated joint with string demonstrating infraspinatus muscle attachments, C. Articulated joint in abduction demonstrating ball-and-socket joint, D. Disarticulated distal (end) scapula and proximal (top) humerus demonstrating ball-and-socket joint

2.1.3.1.2 Cubital (Elbow) Joints

- *Canine*: Due to the limited ability of canines to rotate their forearm (supination and pronation), and the natural congruency of the bones involved, very little alteration needed to be done to this joint. The radius and ulna were fixed together with epoxy and aluminum rods and a circular path was built through the proximal (top) portion of the ulna and distal (bottom) humerus so that a wire could be passed through and fixed together on the caudal (back) aspect of the elbow joint to create a loop (Figure 7). The joint was held together with this wire and the congruency of the bones along with collateral ligaments simulated with elastic stabilized the joint.

Figure 7: Articulated canine cubital (elbow) joint (radius not pictured)

- *Human*: The ability of the human arm to perform significant rotation of the forearm (supination and pronation) made the articulation of this joint, as well as the joints between the radius and ulna, much more difficult than the canine skeleton. The mechanism with the canine humerus and ulna was again implemented with the human elbow to allow for its primary motions – flexion and extension. Additional holes were built into the proximal (top) ulna just distal to (below) the circular path for the wire. These holes were used to stabilize the two ends of a wire that looped around the radius just distal to the articular circumference, imitating the annular ligament (Figure 8).

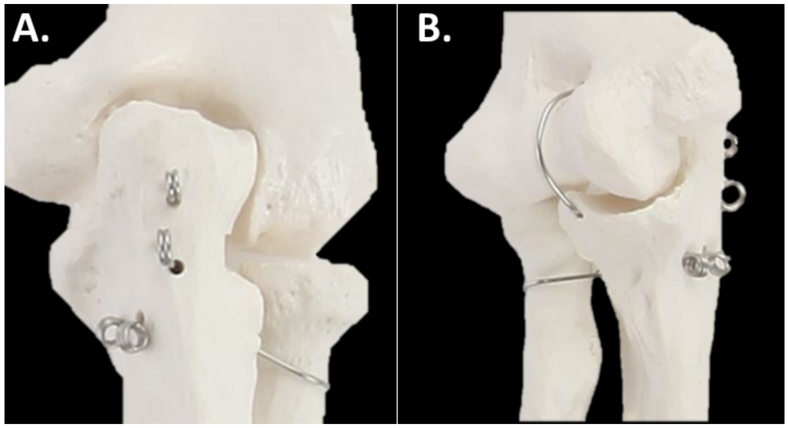

Figure 8: Articulated human cubital (elbow) joint, A. Posterior (back) view, B. Anteromedial (inside front) view

2.1.3.1.3 Carpal (Wrist) Joints

- *Canine*: Canines' limited ability to move the carpal (wrist) joints side-to-side (abduction and adduction) and the limited ability to rotate the forearm (supination and pronation) allowed for the carpal (wrist) joints to be articulated with the same technique used at the canine shoulder joint (Figure 9). Due to the very limited movement that happens at the more distal carpal joints (the middle carpal joint and the carpometacarpal joint) in life, it was determined that the entirety of movement at the carpus (wrist) would occur at the most proximal joint (antebrachiocarpal joint).

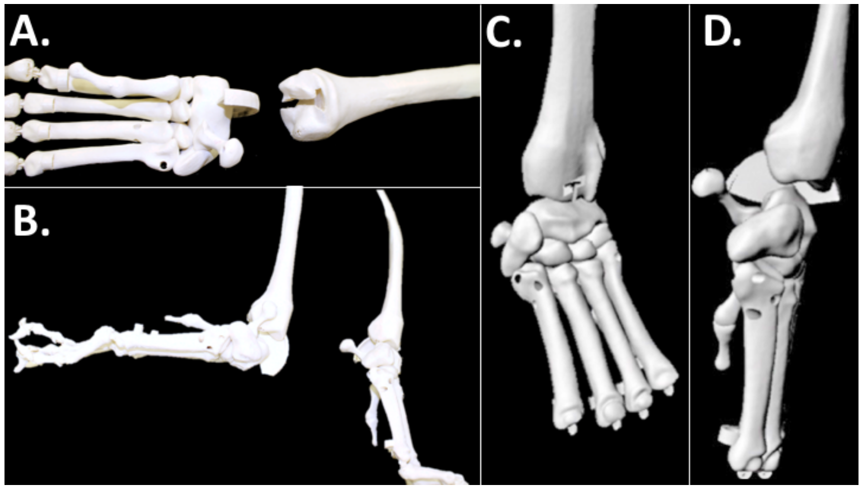

Figure 9: Canine carpal (wrist) joint, A. Disarticulated distal (end) radius and proximal (top) manus (front paw) demonstrating customized joint, B. Articulated joint demonstrating range of motion in the sagittal plane (flexion – left and extension – right), C. Cranial (front) view of 3D animation software rendering of articulated joint demonstrating slight adduction, D. Medial (inside) view of 3D animation software rendering of articulated joint

- *Human*: To allow for side-to-side movement as well as rotation of the forearm, the carpal (wrist) joints on the human arm required slightly more complicated alterations. The distal ends of the ulna and radius were individually and loosely fixed to a small metal plate on the distal articulating surface of both bones. This, along with the mechanism holding the proximal radius and ulna together, allowed for rotational movements of the forearm (supination and pronation). To attach the hand to the forearm, a loop, made from a wire, was placed at the proximal-most (top) part of the carpus. A second loop, also made from wire, went through the metal plate to which the radius and ulna were already attached. Running the loop on the carpus through the loop on the metal plate allowed for a full range of motion at the carpus (wrist) (Figure 10). Again, the entirety of the movement at the wrist joint (flexion and extension) happened at the most proximal joint (antebrachiocarpal joint).

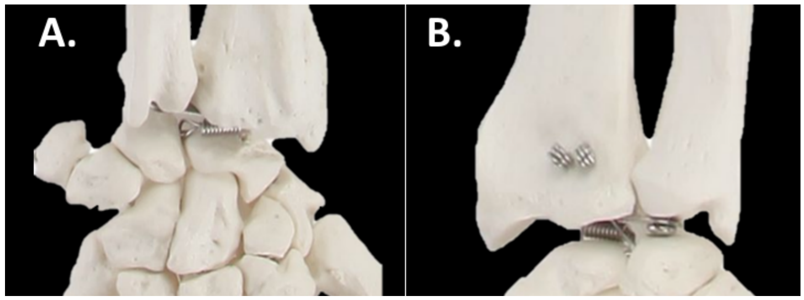

Figure 10: Articulated human carpal (wrist) joint, A. Posterior (back) view, B. Anteromedial (inside front) view

2.1.3.1.4 Digital Joints

All digital joints were created by embedding barrel hinges into the proximal and distal ends of the metacarpals and phalanges. Fishing wire and epoxy were used to connect the top and bottom portions of the barrel hinges. Some over-extension was allowed so that concepts would be easily illustrated to students, but the natural congruency of the bones limited this motion (Figures 11 and 12).

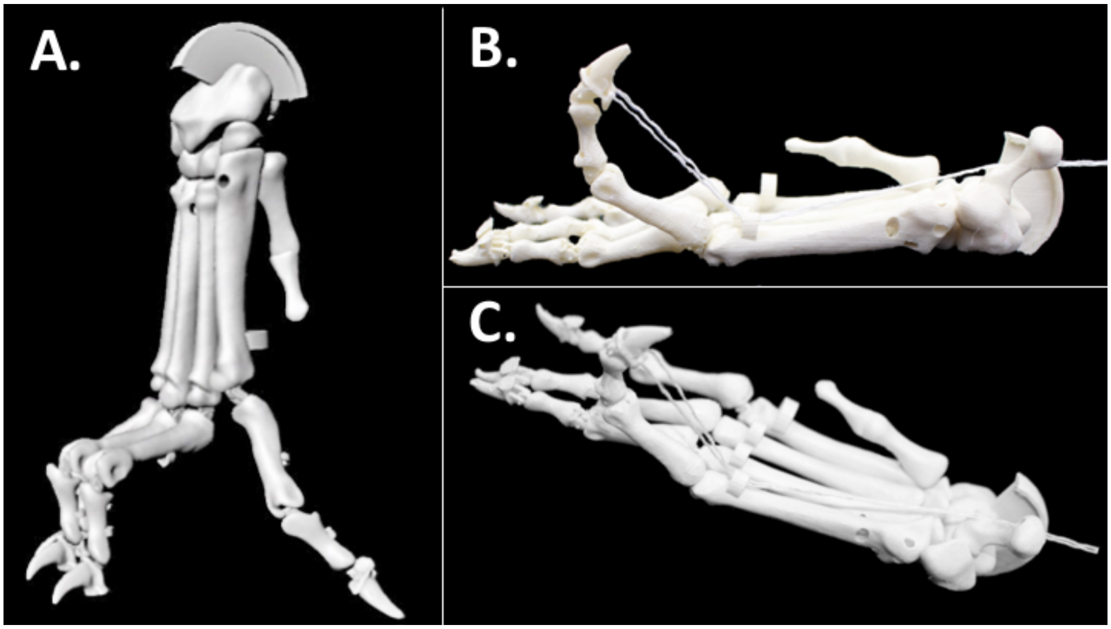

Figure 11: Canine digital joints, A. 3D animation software rendering of manus (front paw) and digital joints demonstrating flexion of the second metacarpophalangeal joint B. Lateral view of canine manus (front paw) and digital joints demonstrating flexion of the digital joints of the fifth digit, C. Caudolateral view of canine manus (front paw) and digital joints demonstrating flexion of the digital joints of the fifth digit

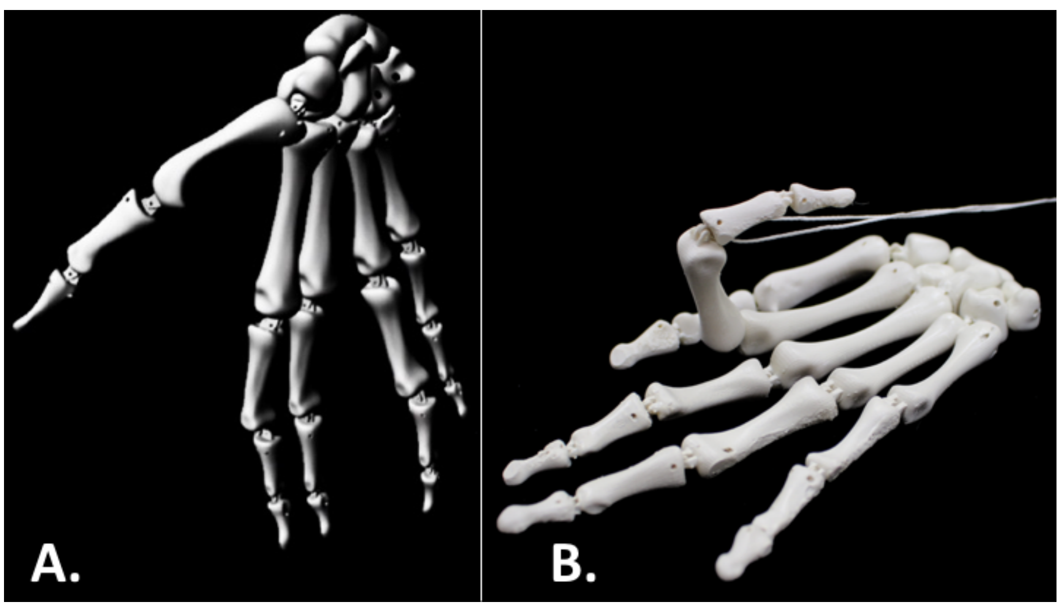

Figure 12: Human digital joints, A. 3D animation software rendering of the hand and digital joints demonstrating extension at the first metacarpophalangeal joint and opposition at the fourth and fifth metacarpophalangeal joints B. Human hand and digital joints demonstrating flexion of the digital joints of the second digit

2.1.3.2 Functional Ligaments and Retinacula

Where it was appropriate, retinacula functioning to bind down tendons were built into the 3D printed models. When a more substantial or flexible retinaculum was necessary (i.e. the transverse humeral retinaculum), a small piece of plastic tubing was fixed to the bone in the appropriate area (intertubercular or bicipital groove) and the string representing the appropriate muscle (biceps brachii muscle) was run through the tubing before being attached to its insertion site. Other ligaments, such as the collateral ligaments of the elbow joint, were simulated with elastic bands which were reinforced with fabric glue. These simulated ligaments were intended not only to provide familiar reference points for students, but also to provide support and stability for the joints during movement.

2.1.3.3 Non-Interactive Structural Muscles

The fleshy portions, or bodies, of both the supraspinatus muscle and the infraspinatus muscle were built into the model of both the human and canine scapula (Figure 13). This was intended to provide more surface area for the strings simulating the muscles to attach to as well as more substance to the bone for the purposes of fixing it to the stand. As the limbs were fixed to the stand on their medial (canine) or anterior (human) surface, the subscapularis muscle was not represented as an interactive simulated muscle. Instead, the tendon of the subscapularis muscle was represented with an elastic band to provide reference and stability to the shoulder joint.

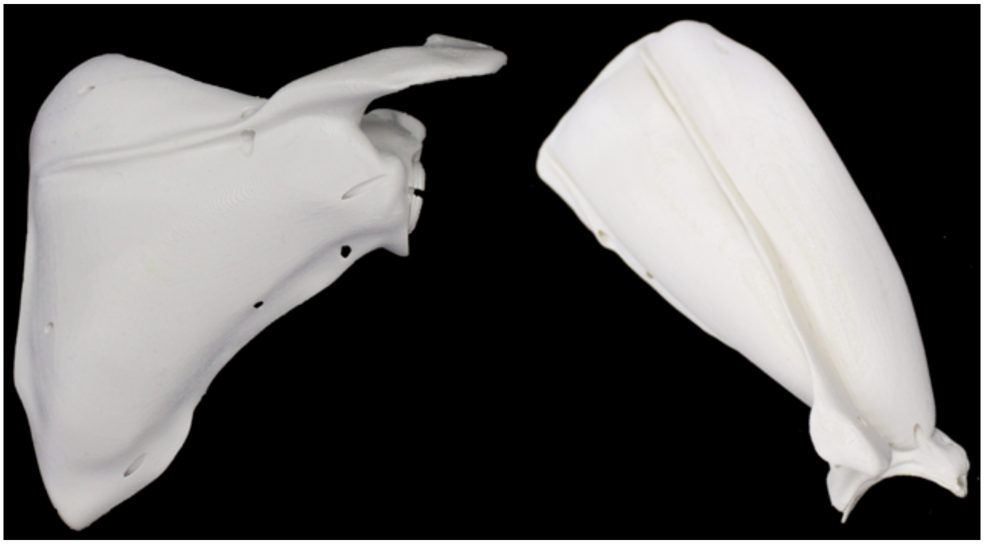

Figure 13: Printed models of human (left) and canine (right) scapulae with altered joint articulations, holes for muscle attachment and fleshy portions of the supraspinatus and infraspinatus muscles

2.1.3.4 Interactive Muscles for Thoracic Limb Myology and Basic Biomechanics Concept Illustration

To provide students a fun and simple means of interacting with the model and illustrating biomechanical concepts, each of the major muscle groups was represented with a set of colored strings. Each group was represented in a different color to further emphasize their unique characteristics and to more easily refer to the unlabeled strings during interaction. The colors chosen for each group were chosen based on previous models' design (Malone, et al, 2019; Malone et al, 2017; Malone, Pine & Bingham, 2016) (Table 1 and Figure 14).

Muscle Group	Working Muscles - Human	Working Muscles - Canine
Lateral Shoulder Muscles	• Supraspinatus • Infraspinatus • Deltoid (all three heads) • Teres Minor	• Supraspinatus • Infraspinatus • Deltoideus (both heads) • Teres Minor
Medial Shoulder Muscles	• Teres Major	• Teres Major
Elbow Flexors	• Biceps Brachii • Brachialis • Brachioradialis	• Biceps Brachii • Brachialis
Elbow Extensors	• Triceps Brachii (long head) • Triceps Brachii (lateral and medial heads)	• Triceps Brachii (long head) • Triceps Brachii (lateral, accessory, and medial heads)
Carpal Extensors	• Extensor Carpi Radialis (both heads) • Extensor Digitorum • Extensor Digiti Minimi • Extensor Carpi Ulnaris • Extensor indcis	• Extensor Carpi Radialis • Common Digital Extensor • Lateral Digital Extensor
Carpal Flexors	• Palmaris Longus • Flexor Carpi Ulnaris • Flexor Digitorum Superficialis* • Flexor Digitorum Profundus • Flexor Carpi Radialis	• Flexor Carpi Radialis • Superficial Digital Flexor • Deep Digital Flexor • Flexor Carpi Ulnaris
Axial Movers of the Forearm	• Pronator Teres (humeral head) • Supinator	• Ulnaris Lateralis

**humero-ulnar head origin, all insertions*

Table 1: Muscle groups and their corresponding muscles highlighted in the same color as the strings representing muscles on the model

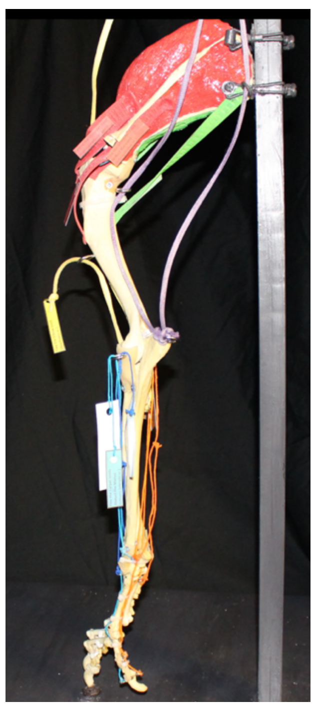

Figure 14: Model from Malone et al, 2019 demonstrating muscles represented by string colored by group (Malone et al, 2019)

For each muscle represented, an origin hole and an insertion hole were built into the appropriate boney structures. The string meant to represent a muscle was first threaded through the hole representing the muscle's origin, then through any retinacula that it was associated with, and finally threaded through the insertion hole and fixed in place with epoxy (Figure 15). A short loose end of the string at the origin of each muscle was attached to appropriately colored beads so that it would not fall through and could be easily identified. When this loose end and beads are pulled, the action of the corresponding muscle is created. Strings simulating muscles were not labeled beyond the color-coding of muscle groups so that students are not able to simply look up the muscle in their lab guide to determine its characteristics. Instead they had to pull the string to determine the action and work from there to determine which muscle is being represented. Simulated muscles which were used for the in-lab model activity could be identified by the number of the corresponding questions on a laminated card attached to the end of the muscles' string.

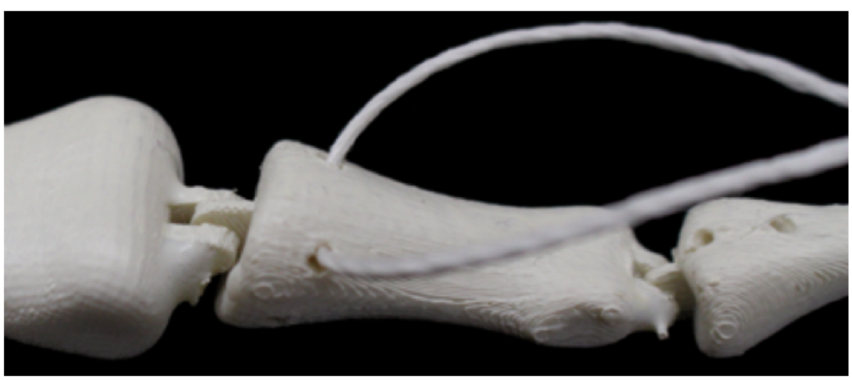

Figure 15: Canine middle phalanx demonstrating attachment point for a muscle built into 3D printed model

2.1.3.5 Muscle to Bone Attachment Models

In order to demonstrate concepts related to the different ways in which muscles attach to bone, separate muscle attachment models were created. To allow multiple groups of students to interact with the models simultaneously, seven sets of these models were made. Each set included three canine bones, each demonstrating one of the three ways in which muscle attaches to bone:

- Scapula demonstrating the fleshy origin of the supraspinatus muscle
- Humerus demonstrating the aponeurotic origin of the lateral head of the triceps brachii muscle
- Ulna demonstrating the tendinous insertion of all heads of the triceps brachii muscle

The bones for these models were a combination of real canine bones and bones cast in plastic resin. The fleshy attachment was created using felt and Velcro on the supraspinous fossa of the scapula (Figure 17B). An aponeurotic attachment was created using a small piece of a shower curtain sewn and glued along the boney ridge of the tricipital line on the humerus (Figure 17C). Finally, a tendinous attachment was created by screwing a heavy-duty piece of elastic onto the olecranon of the ulna (Figure 17D).

2.1.3.6 Thoracic Limb Myology and Basic Biomechanics In-Laboratory Activity

After assembly, flexor and extensor surfaces for all joints were painted and labeled for reference (red labeled “B” for flexor surfaces and blue labeled “A” for extensor surfaces). In addition, a red eyehook, (on the anterior aspect of the metacarpus for the human and on cranial surface of the humerus for the canine), and a blue eyehook, (on the anterior aspect of the radius for the human and the cranial aspect of the scapula for the dog), were fixed to the skeletons for demonstration of concepts related to origins and insertions of muscles.

The main model with the human and canine limb was rolled into the small laboratory room which is connected to the larger laboratory room in which the students complete their dissection (Figure 16). Muscle attachment model sets were laid out in the back of the larger laboratory room so that multiple groups of students could interact with them at the same time without hindering the interaction with the biomechanical models (Figure 17). The Thoracic Limb Myology & Basic Biomechanics In-Lab Activity in its entirety can be seen in Appendix A.

Figure 16: Model with human and canine limbs set-up for interaction in small laboratory room

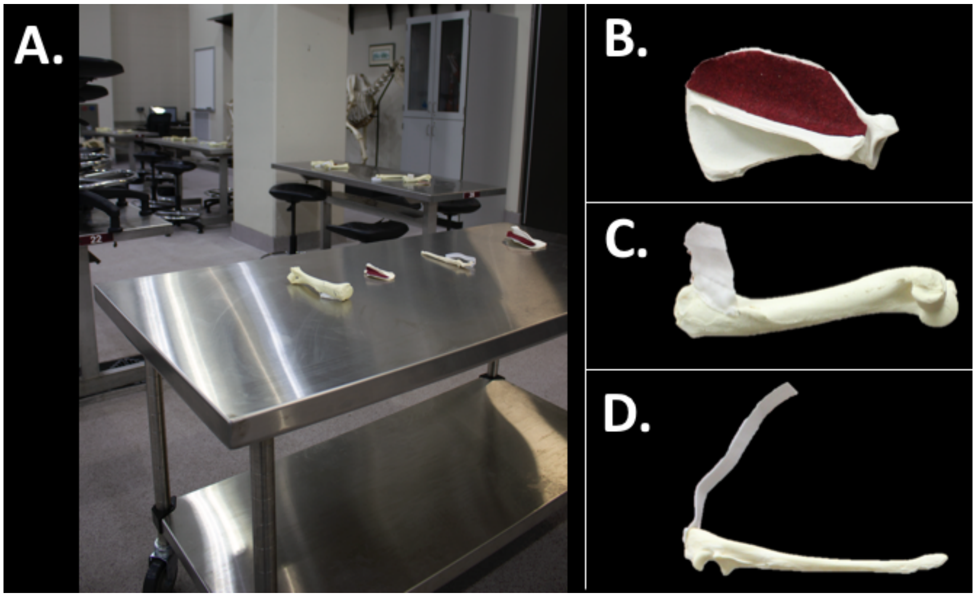

Figure 17: Muscle attachment models, A. Model sets laid out for interaction in the back of the large laboratory room, B. Scapula model demonstrating fleshy attachment, C. Humerus model demonstrating aponeurotic attachment, D. Ulna model demonstrating tendinous attachment

2.1.3.6.1 Activity Design

Students were asked to use either the human or canine limb model or the muscle attachment models to complete the following tasks in their dissection groups (3-4 students) (Figure 18):

- Identify the flexor surfaces of joints by circling either "Blue (A)" or "Red (B)"
- Run a shoelace provided to them through a blue eyehook and loosely tie it to the corresponding red eyehook, pull the shoelace and report which eyehook moves the most
    - Indicate which eyehook represents the insertion of the theoretical muscle by circling either "Red" or "Blue"

- Refer to a specifically labeled string and indicate whether the muscle being represented crossed the flexor surface and/or the flexor angle of the shoulder, elbow, and wrist/carpal joints
- Refer to another specifically labeled string and report the action of the muscle and the group it belongs to
- Demonstrate concepts of agonist, antagonist, synergist, and fixator by pulling and letting go of specifically labeled strings in an indicated order
- Indicate whether models were demonstrating aponeurotic, fleshy or tendinous
- Indicate whether models were demonstrating an origin or an insertion
- Indicate which muscle's attachment the models were demonstrating

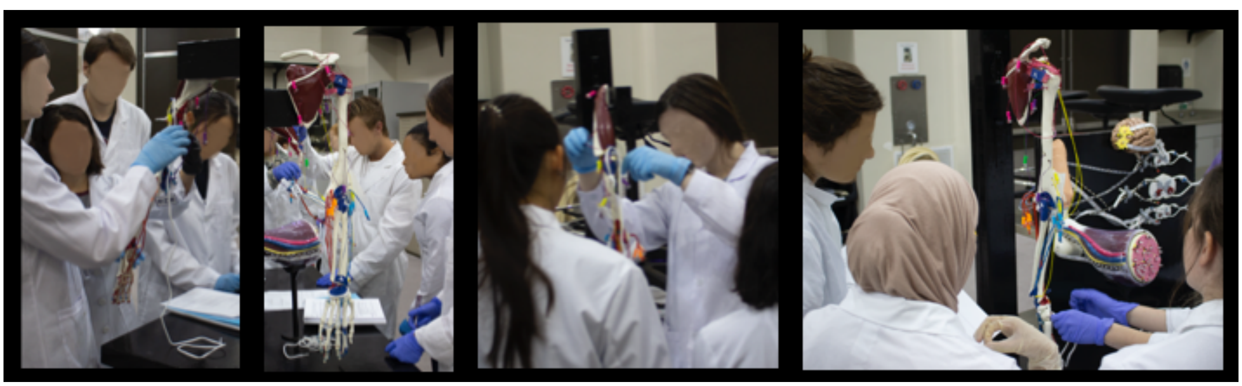

Figure 18: Students interacting with model to demonstrate biomechanical concepts

2.1.4 Skeletal Muscle Architecture and Innervation for Histological, Physiological and Neuroanatomical Concept Illustrations

With the exception of the 3D models of the brain and brainstem (which was downloaded from turbosquid.com) and LED lights, the following structures were designed and printed for use in this portion of the model:

- One brain (cerebrum and cerebellum) and brainstem hemisphere model
- 18 spinal cord segments with bilateral spinal nerve roots and branches
- 22 multipolar neuronal cell bodies for alpha motor neurons and upper motor neurons
- 20 pseudounipolar neuronal cell bodies for somatic afferent neurons (Figure 34)
- One human brachium (upper portion of the arm) - half covered with simulated flesh, including the skin, half only bone (Figure 21C)
    - Skin is created using pigmented Dragon Skin^{TM} Silicone (from Smooth-On.com)
- One enlarged skeletal muscle arising from the bony portion of the humerus, with accompanying neurovascular bundle, cut in cross-section to show fascicles and muscle cells (Figure 21A)
    - Epimysium is represented on the skeletal muscle with unpigmented Dragon Skin^{TM} Silicone (from Smooth-On.com) (Figure 19)
- 33, 5mm LED lights with built-in resistors (from SparkFun Electronics Inc.)
    - two yellow LED lights for upper motor neurons
    - three blue LED lights for somatic afferent neurons
    - 28 red LED lights for alpha motor neurons and muscle cells

- Six Adafruit NeoPixel Digital RGB LED Strips for neuronal fibers (from Adafruit Industries)
    - Two white insulated strips for myelinated fibers (Figure 20A)
    - Four uninsulated strips for unmyelinated and diseased fibers (Figure 20C)
- Five multicolored tactile buttons (from SparkFun Electronics Inc.)
    - Two yellow buttons for upper motor neurons
    - Three red buttons for alpha motor neurons
- Two square force sensitive resistors (pressure sensors) for somatic sensory recognition (from SparkFun Electronics Inc.) (Figure 21B)
- One ARDUINO® MEGA 2560 microcontroller board
- One prototyping board
- Numerous connectors and connecting wires

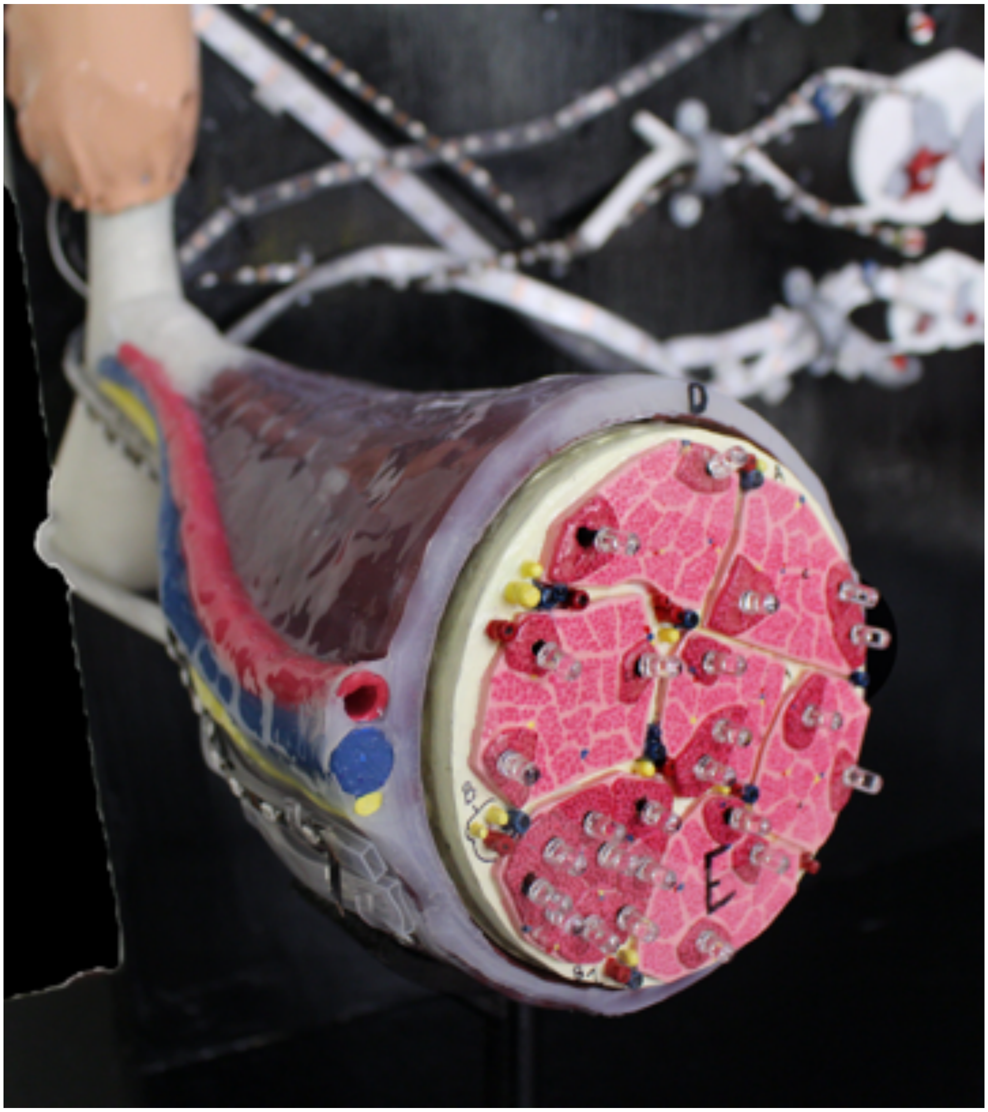

Figure 19: Enlarged skeletal muscle model with accompanying neurovascular bundle, cut in cross-section to show fascicles and muscle cells

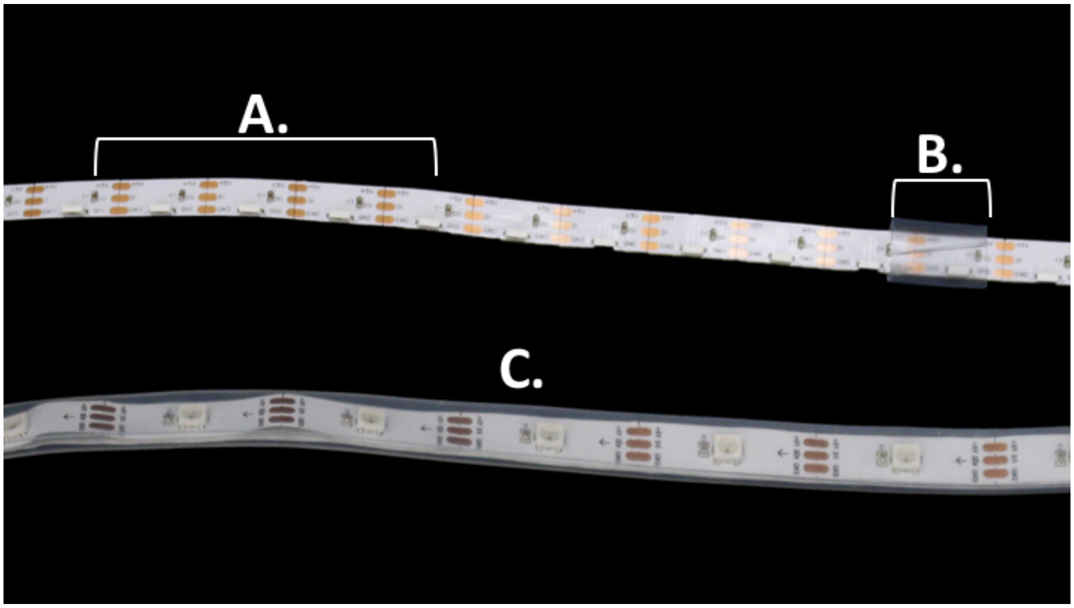

Figure 20: Adafruit NeoPixel Digital RGB LED Strips used to represent neuronal fibers, A. Uninsulated strip used to represent unmyelinated fibers, B. Plastic tubing used to sparsely cover uninsulated strips to represent diseased fibers, C. Insulated strip used to represent myelinated fibers

The brain hemisphere and spinal cord segments were mounted in the middle of the large vertical stand of the model. Two yellow multipolar neuronal cell bodies, each along with a yellow button and yellow LED light, were mounted to the brain hemisphere. One red multipolar neuronal cell body and one blue pseudounipolar neuronal cell body was mounted, along with a push-button and LED light of the same color, to the appropriate regions on the spinal cord segment or spinal nerve models. The remaining spinal cord segments and neuronal cell bodies were used to create 15 stand-alone spinal cord segment models to facilitate multiple groups' interaction without hindering interaction with the larger model (Figure 34B). Twenty-five of the individual muscle cells shown in the cross-sectional model of the skeletal muscle were fixed with a red LED light (Figure 21A).

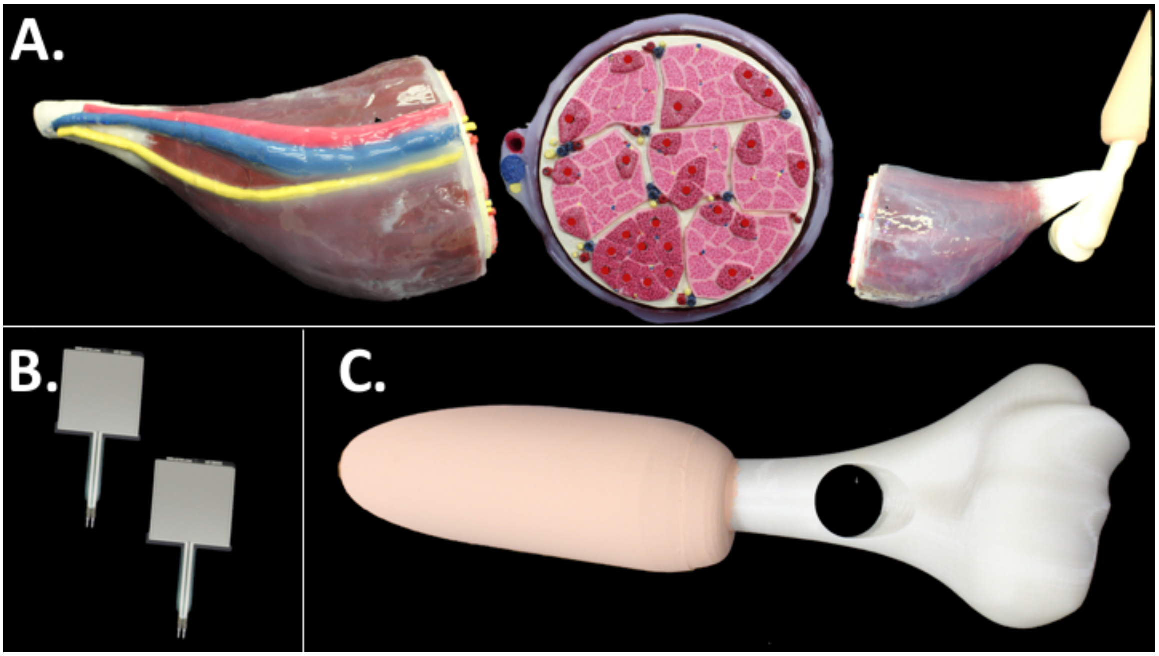

Figure 21: Components of model for skeletal muscle histology & neuroanatomical concept demonstration, A. Enlarged skeletal muscle model with accompanying neurovascular bundle, cut in cross-section to show fascicles and muscle cells, B. Pressure Sensors mounted on human brachium for somatic sensory recognition, C. Human brachium (upper portion of the arm) half covered with flesh, including the skin, half only bone with hole to support muscle model

2.1.4.1 Motor Neuron Design and Interaction

The last (bottom) spinal cord segment and spinal nerve included the neuronal cell bodies associated with a myelinated peripheral nerve. The second spinal cord segment and spinal nerve included neuronal cell bodies associated with an unmyelinated peripheral nerve. Finally, the first (top) spinal cord segment and spinal nerve included neuronal cell bodies associated with a spinal nerve affected by a demyelinating disease (spinal cord segments referred to here can be seen in Figure 4). The two multipolar neuronal cell bodies at the brain and brainstem represent upper motor neurons.

Upon pressing the button associated with one of these upper motor neurons, the yellow light it is associated with turns on, then a signal is seen passing along the axon (represented by an LED light strip) to one of the alpha motor neurons located in a spinal cord segment (Figure 22A). That alpha motor neuron's cell body lights up red, then sends a signal along its own axon to the enlarged skeletal muscle model (Figure 22B). Certain muscle cells that are assigned to that alpha motor neuron then light up red, representing depolarization of those cells within the alpha motor neuron's motor unit (Figure 22C). The second upper motor neuron does not light up yellow, nor does it send a signal down the spinal cord. This was used as an illustration alongside a case-study.

Upon pressing the red button associated with any of the alpha motor neurons within the spinal cord segments, the red light turns on, then a signal is sent along the axon of that neuron to the enlarged muscle model. The muscle cells in the motor unit associated with that alpha motor neuron then light up red. The speed of the signals traveling along each axon is appropriate to the type of nerve that it is associated with (i.e. myelination).

2.1.4.2 Sensory Neuron Design and Interaction

Pressure sensors are fixed to the human brachium just beneath the simulated skin. When these sensors are activated, a signal is seen passing from the skin into the spinal nerve branch and root, past the neuronal cell body (which lights up blue as the signal passes), and into the spinal cord (Figure 22D).

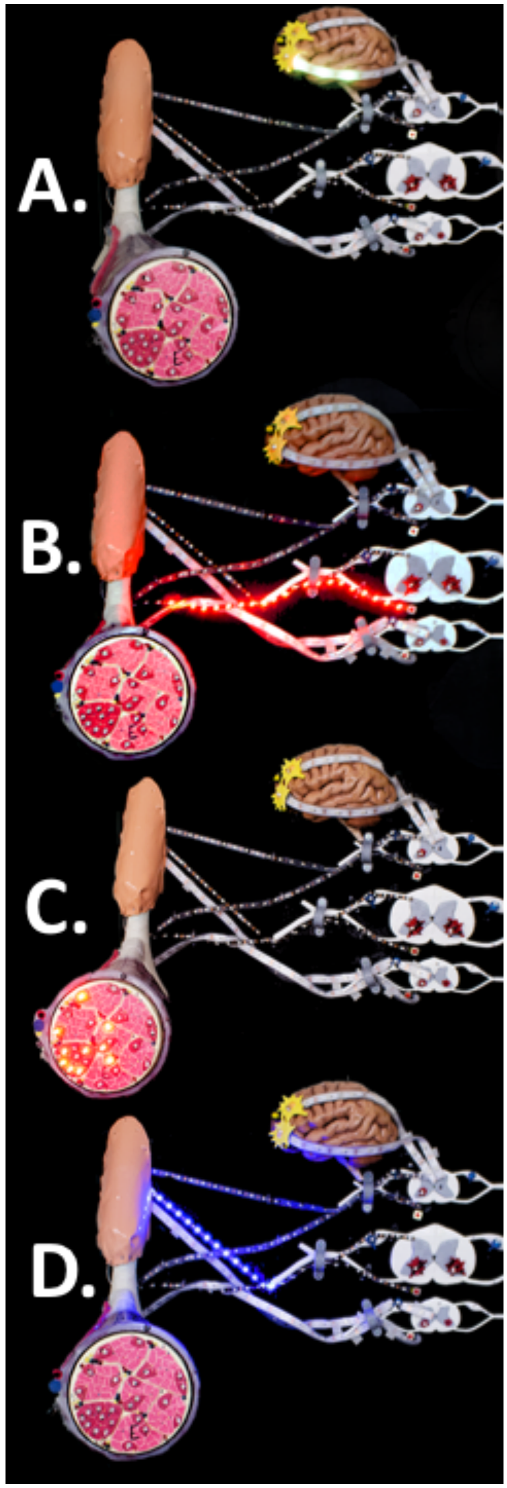

Figure 22: Skeletal muscle architecture and innervation for histological and neuroanatomical concept illustration, A. Upper motor neuron signal being sent to spinal cord segments, B. alpha motor neuron signal being transmitted to muscle cells, C. Muscle cells within a particular motor unit lighting up to represent depolarization, D. Somatic efferent signal being sent from skin into the central nervous system

2.1.4.3 Sarcomere for Skeletal Muscle Physiology Concept Illustration

The following components of a sarcomere were designed and printed or purchased for use in this portion of the model:

- Two Z-Discs (decagons) with custom supports and holes for thin filaments (Figure 23 and Figure 24B, D, and E)
- Two multicolored tactile buttons – one blue and one yellow (from SparkFun Electronics Inc.)
- One custom box stand (Figure 30)
- Four small caster wheels (Figure 24E)
- 16 thin filaments (actin portion only)
- 32 troponin molecules (Figure 24A)
    - Ten of these troponin molecules had a small magnet inside of the troponin-C portion
- 32 Tropomyosin molecules made from yellow ribbon (Figure 24F)
- 30+ calcium ions (Figure 25E)
    - 5 of these calcium ions had magnets corresponding to those inside of the troponin-C molecules
- One large barrel with seven myosin bodies
- One M-line
- 24 pairs of myosin heads
- Two standard size generic high torque servo motors (FS106B from SparkFun Electronics Inc.) (Figure 26B)

- One custom box with front-open door, lid, and push-button acetylcholine "receptor" (Figure 25A and B)
- Two idealized acetylcholine (ACh) molecules (Figure 25C)
- Two idealized tubocurarine molecules (Figure 25D)
- 200+ short thick wooden dowels painted with A bands, I bands and Z Discs (eight per activity set) for contracted skeletal muscle cells
- 300+ long thin wooden dowels painted with A bands, I bands and Z Discs (fifteen per activity set) for relaxed skeletal muscle cells
- Plastic wrap for endomysium
- Aluminum Foil for perimysium
- 50+ containers of Play-Doh (1-2 per activity set) for epimysium
- Yellow yarn for alpha motor neuron axons
- Seven to eight pairs of safety scissors
- Seven to eight roles of clear tape for neuromuscular junctions (Figure 27)
- One ARDUINO® UNO microcontroller board
- One prototyping board
- One 4 Cell AA Battery Holder with JR Style Connector Receiver (From Apex RC Products)
- Four AA batteries
- Various connecting wires (Figure 26A)
- Blue, orange, and green yarn (Figure 28B)

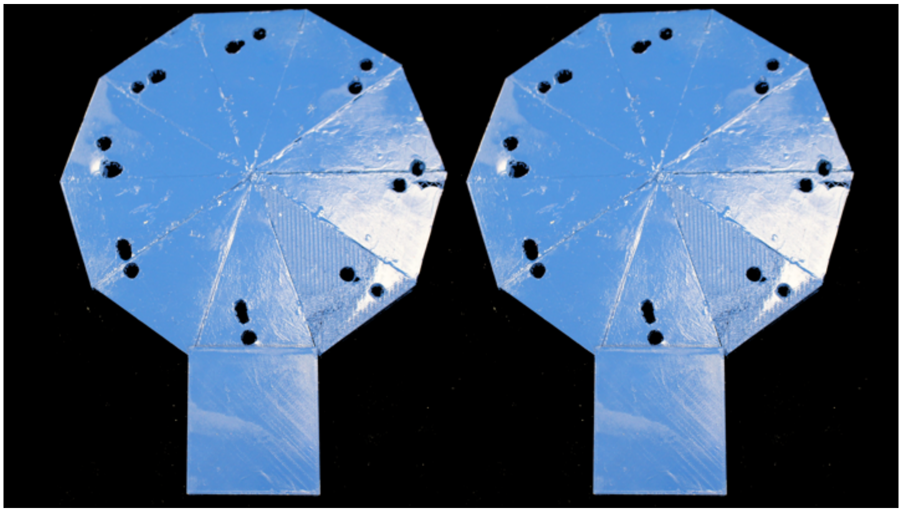

Figure 23: Z-discs

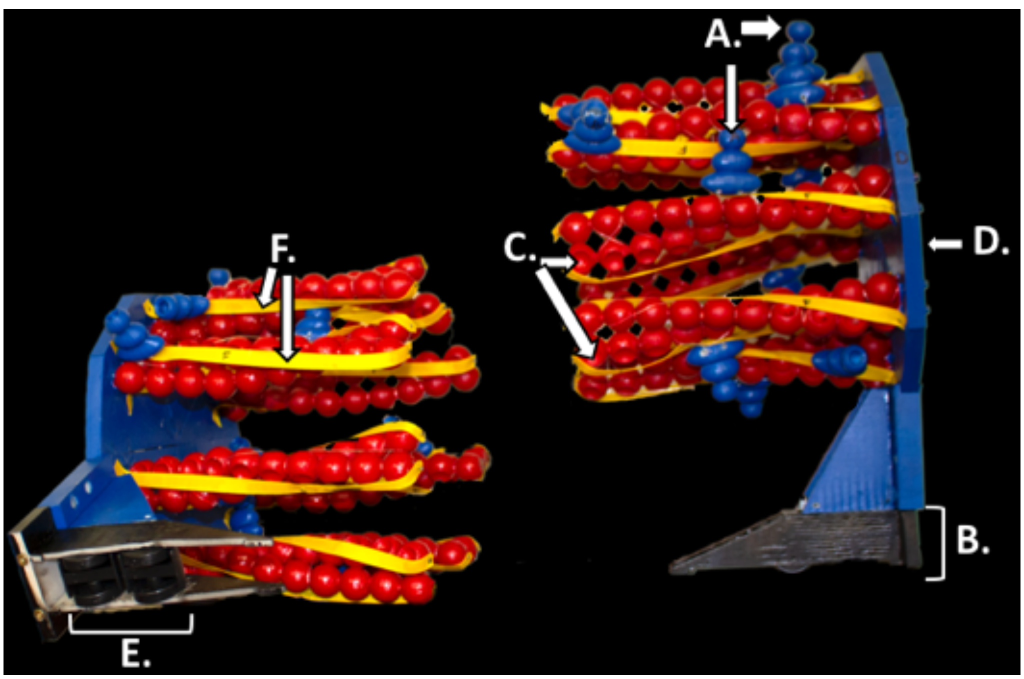

Figure 24: Assembled Z-discs and thin filaments, A. Troponin molecules, B. Customized support and wheel housing for Z-Discs, C. Actin molecules with active sites, D. Z-Discs, E. Castor wheels, F. Tropomyosin molecules

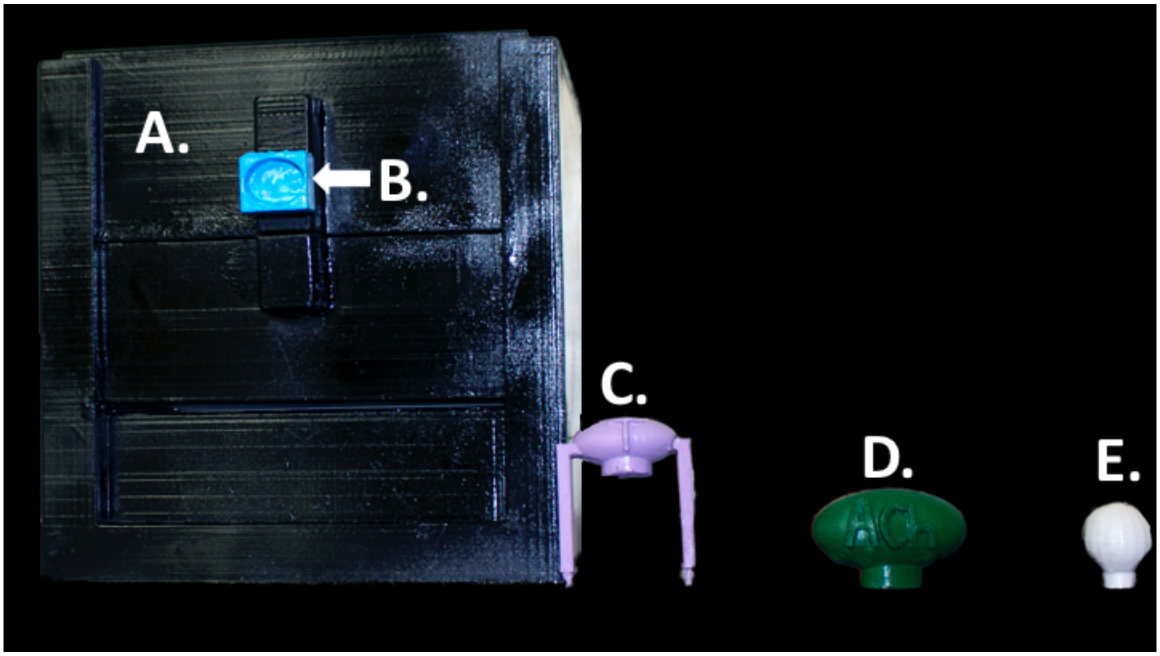

Figure 25: Neuromuscular junction model, A. Custom box with drop-down, front-facing door and lid representing the combined and idealized structures of the sarcolemma, T-tubules and sarcoplasmic reticulum of a muscle cell, B. Push-button idealized ACh receptor, C. Idealized tubocurarine molecule (muscle relaxant), D. Idealized ACh molecule, E. Calcium ion

The bottom of each troponin molecule was fixed to the tropomyosin molecules at various points along the ribbons using fishing wire and fabric glue. Fishing wire was also used to loosely fix tropomyosin molecules to the actin portions of the thin filaments. Eight thin filaments were attached to each Z-disc with joints built into the models and epoxy for support. Two servo motors were mounted inside of the barrel for the myosin bodies and string was run through holes in the barrel to each pair of myosin heads. One myosin head was attached to each end of each myosin body with joints built into the models which allow the myosin heads to rotate up and down when the string pulls on them (Figure 26B). The M-line and stands on the Z-discs fit into specially designed slots on a 3D printed stand for the sarcomere. This 3D printed stand also has specially designed areas to conceal electronics used in the model (Figure 26A).

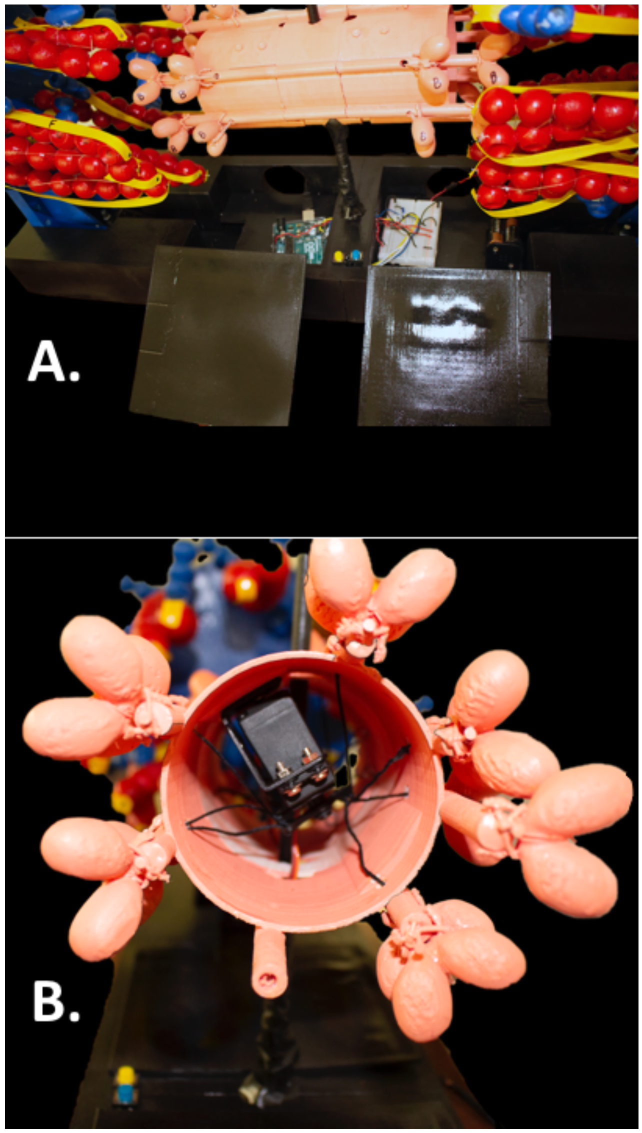

Figure 26: Electrical internal structure of sarcomere model, A. ARDUINO® UNO, prototyping board, batteries, and other electronic components inside concealed area with covers, B. Servo motor mounted inside of barrel with myosin bodies and strings used to pull myosin heads

2.1.4.4 Skeletal Muscle Histology and Physiology In-Laboratory Activity

After assembly, each component of the sarcomere model was labeled with a letter as follows so that students were able to refer to the different portions:

- Troponin (specifically troponin C)
- Myosin (specifically myosin heads)
- Actin (specifically active sites)
- Z-Discs
- Calcium Ions
- Tropomyosin Molecules

Similarly, the enlarged skeletal muscle histology model was labeled as follows:

- Perimysium
- Neurovascular Bundles
- Endomysium
- Epimysium
- Fascicle
- Muscle

Multiple sets of “Muscle Building” activities were assembled so that many groups could complete the activity at once. Each set included 8 contracted muscle cells, 15 relaxed muscle cells, several sheets of plastic wrap and foil, Play-Doh, several pieces of yellow yarn, one pair of safety scissors, and a roll of clear tape. These sets were placed on tables inside of the small laboratory room and were replaced after each group finished the activity (Figure 27).

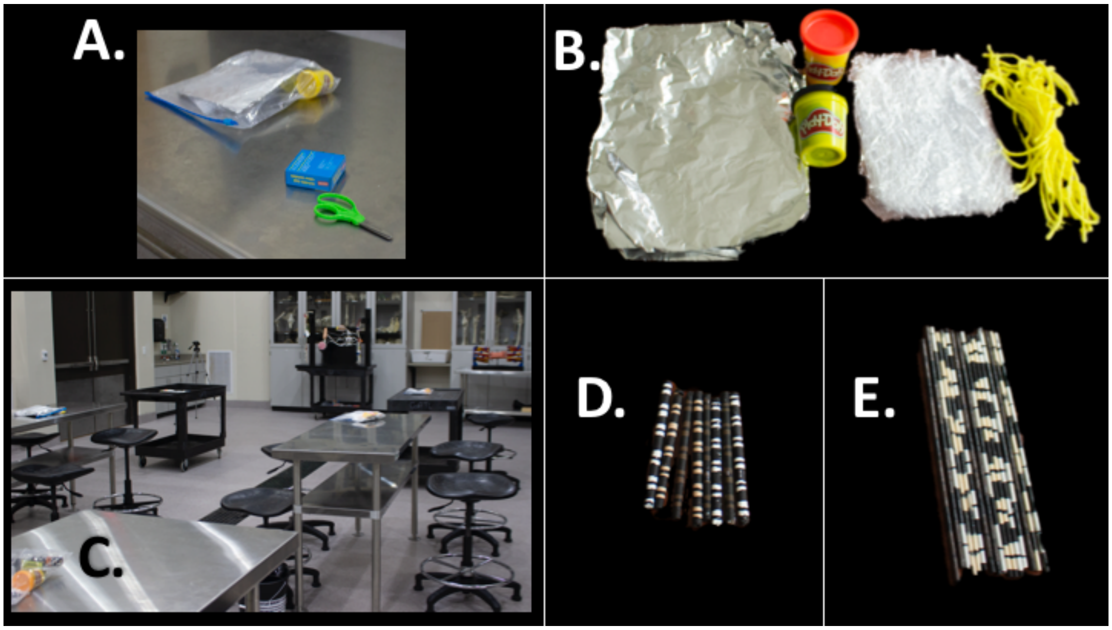

Figure 27: Muscle building activity, A. One full set of materials, B. Aluminum foil sheets, plastic wrap sheets, yellow yarn, and Play-Doh included inside of a single set, C. Multiple sets laid out in small laboratory room opposite larger models, D. Shorter, thicker wooden dowels representing contracted muscle cells, E. Longer, thinner wooden dowels representing relaxed muscle cells

Several sets motor units each consisting of one motor unit with a 1:2 ratio (axon to muscle cells) with an axon made of blue yarn, one motor unit with a 1:4 ratio with an axon made of green yarn and one motor unit with a 1:8 ratio and an axon made of orange yarn were also assembled prior to interaction so that many groups could complete the activity at once. These sets were laid out on tables in the back of the large laboratory room (Figure 28).

Figure 28: Motor units, A. Motor unit sets laid out in the back of the large laboratory room, B. A single set of motor units with motor unit ratios of 1:2 (blue), 1:8 (orange) and 1:4 (green)

The main model with the skeletal muscle histology model was rolled into the small laboratory room next to a table with the sarcomere model. These models were on the opposite end of the small laboratory room so that interaction with the larger models did not interfere with other activities (Figure 29). The Skeletal Muscle Histology and Physiology In-Lab Activity in its entirety can be seen in Appendix A.

Figure 29: larger models of skeletal muscle histology (left) and sarcomere (right) set-up in large laboratory room opposite muscle building activity

2.1.4.4.1 Activity Design

Students were asked to use either the skeletal muscle histology model, the "Muscle Building" activity models, or the motor unit models to complete the following tasks in their dissection groups (3-4 students) (Figures 30-33):

- Identify, by letter, the different components of skeletal muscle histology
- Work through the physiological method of skeletal muscle contraction
    - Place the calcium molecule inside of a troponin molecule
    - Use the calcium-troponin complex to move tropomyosin off the active sites on actin
    - Rotate myosin heads so that they are near active sites by pressing the blue button
    - Push Z-Discs together and continue to rotate myosin heads
    - Use the yellow button to rotate myosin heads back to the original position
- Identify, by letter, the different components of the sarcomere model
- Determine, by letter, which component of the sarcomere model can be found inside of the A band
- Determine, by letter, which components of the sarcomere model can be found inside of the I band
- Use components of "Building Muscle Activity" sets to build muscles with particular characteristics:
    - One precisely controlled muscle that is 50% contracted
    - One coarsely controlled muscle that is 25% contracted

- Determine which muscles from the “Building Muscle Activity” are appropriate for various activities
- Use a hypothetical situation to alter recruitment of motor units given specific motor unit ratios

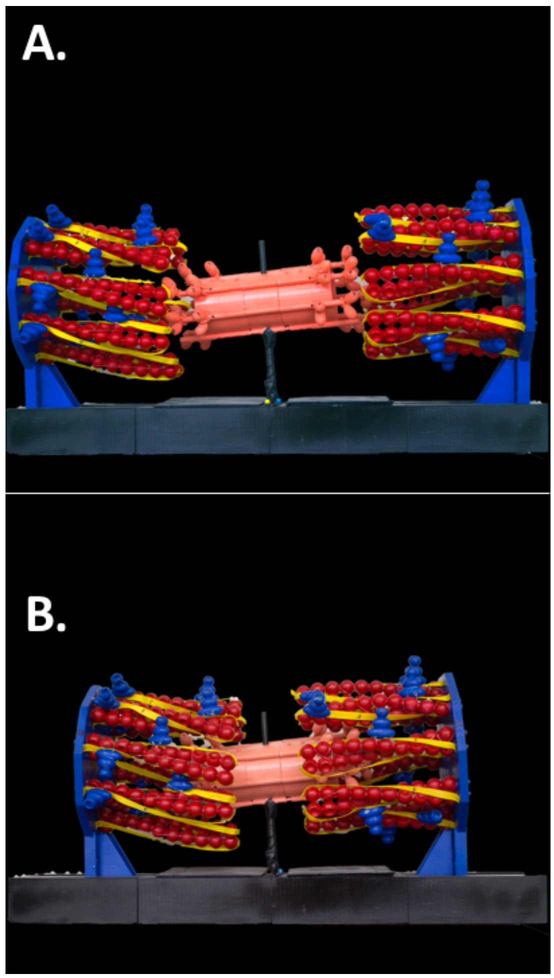

Figure 30: Sarcomere model, A. Sarcomere model in relaxed position, B. Sarcomere model in contracted position

Figure 31: Students interacting with building muscle activity

Figure 32: Students interacting with skeletal muscle histology model

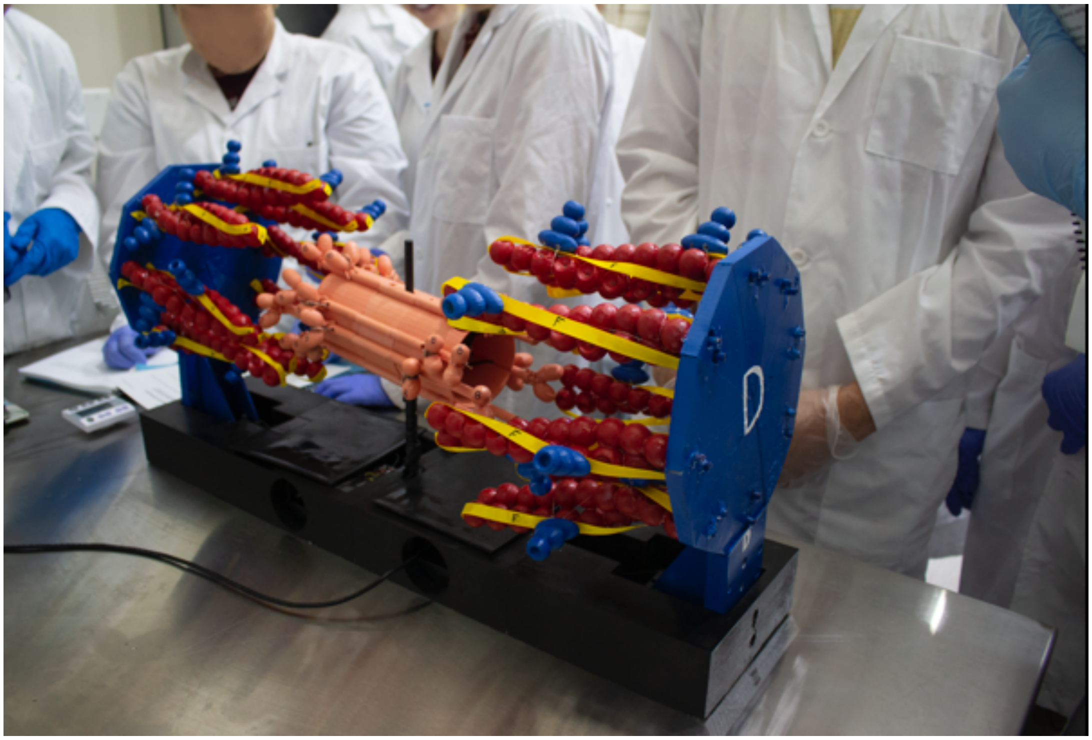

Figure 33: Students interacting with sarcomere model

2.1.4.5 The Peripheral Nervous System In-Laboratory Activity

After assembly, each component of each of the spinal cord segments were labeled with a letter as follows so that students were able to refer to the different portions:

- Pseudounipolar neuronal cell body
- Grey matter
- Ventral root of the spinal nerve
- White matter
- Multipolar neuronal cell body
- Dorsal root ganglion
- Ventral branch of the spinal nerve

- Dorsal root of the spinal nerve
- Dorsal branch of the spinal nerve

The larger model demonstrating efferent and afferent impulses was set up in the small laboratory room. All 15 of the stand-alone spinal cord segments, labeled with letters, were set out on tables in the back of the large laboratory room so that more than one group could work on that portion of the activity at once (Figure 34A). The Peripheral Nervous System In-Lab Activity in its entirety can be seen in Appendix A.

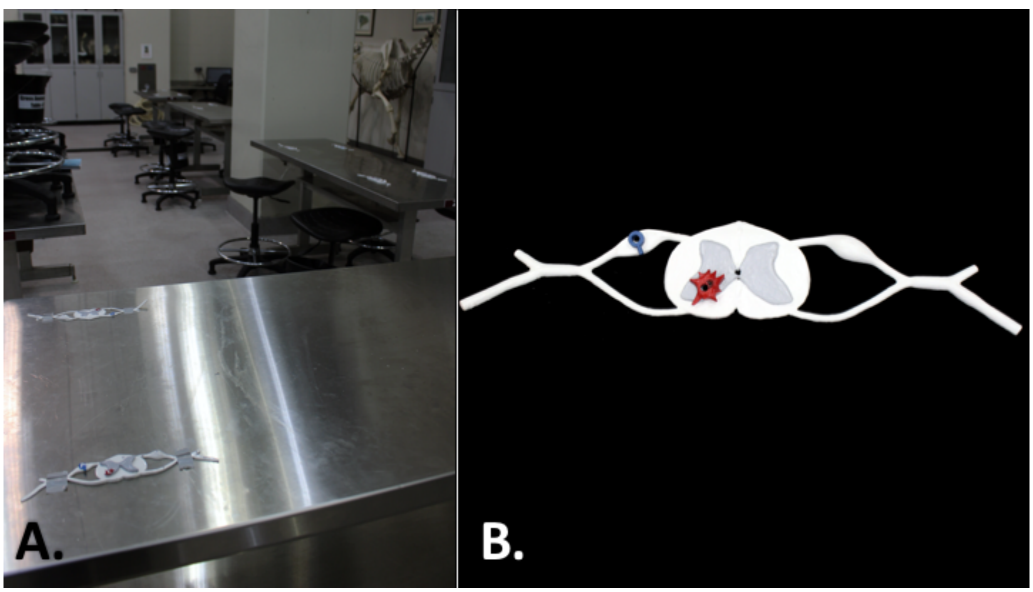

Figure 34: Spinal cord segment models, A. Stand-alone spinal cord segment models set-up in the large laboratory room to facilitate multiple groups, B. A single spinal cord segment model with all components of the spinal nerve, including efferent and afferent neuronal cell bodies

2.1.4.5.1 Activity Design

Students were asked to use either the larger model in the small laboratory room or the stand-alone models at the back of the large laboratory room to complete the following tasks in their dissection groups (3-4 students) (Figure 35):

- Press the skin over the humerus (human brachium) mounted on the back board of the model
    - Indicate the direction of the resulting impulse in regard to the central and peripheral divisions of the nervous system
    - Classify the neuron sending the impulse based on the direction of impulse
    - Classify the neuron as sensory, special sensory, or motor
    - Classify the neuron according to the number of cellular processes
- Press any of the red buttons associated with one of the spinal cord segments
    - Indicate the direction of the resulting impulse in regard to the central and peripheral divisions of the nervous system
    - Classify the neuron sending the impulse based on the direction of impulse
    - Classify the neuron as sensory, special sensory, or motor
    - Classify the neuron according to the number of cellular processes
- Describe the difference in appearance amongst the peripheral fibers of the neurons on the model
- Press each red button (top alpha motor neuron, middle alpha motor neuron and bottom alpha motor neuron) sequentially
    - Indicate which neurons transmitted the signal more quickly
    - Propose a reason for the differing speeds of transmission

- Identify, by letter, the cell body of an afferent, pseudounipolar, neuron
- Identify, by letter, the cell body of an afferent, multipolar, neuron
- Identify, by letter, each of the following portions of the spinal cord segment and indicate which anatomical division of the nervous system it is located in (by circling either PNS or CNS):
    - Body of a pseudounipolar neuron
    - Body of a multipolar neuron
    - Dorsal root of a spinal nerve
    - Dorsal root ganglion of a spinal nerve
    - Ventral root of a spinal nerve
    - Dorsal branch of a spinal nerve
    - Ventral branch of a spinal nerve
    - Grey matter of the spinal cord
    - White matter of the spinal cord
- Indicate, by letter, which areas of the spinal cord segment contains portions of both multipolar and pseudounipolar neurons

Figure 35: Students interacting with nervous system model (students have just pressed the red button associated with the top spinal cord segment)

2.1.5 Integration In-Laboratory Activity

For this activity, each group of students was given a case study on a 28-year-old woman recovering from a Zika infection with suspected Guillain-Barre Syndrome (a rare demyelinating disorder). All relevant disease functions and diagnostic testing details were described in the case study. Students were asked to read and review the case study completely before completing the activity.

The smaller laboratory room was separated into two areas. One area was set up with the sarcomere model as well as the neuromuscular junction model (including the neuromuscular junction box, calcium ions, tubocurarine molecule, and acetylcholine molecule) (Figure 36).

The larger model was set up in the opposite area of the small laboratory room. The Integration In-Lab Activity in its entirety can be seen in Appendix A.

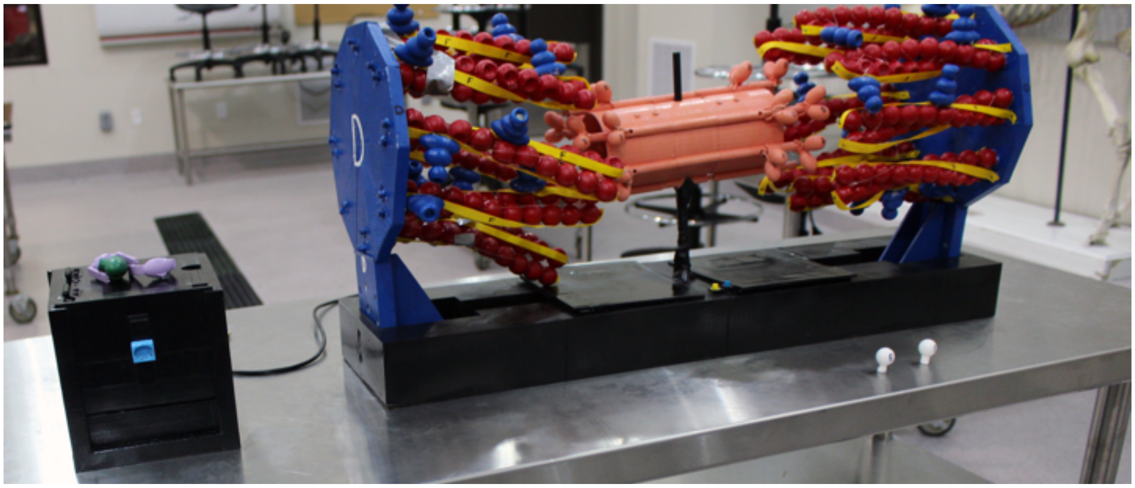

Figure 36: Neuromuscular junction model and sarcomere model set-up in small laboratory room

2.1.5.1 Activity Design

Students were asked to use either the large model, the sarcomere model or the neuromuscular junction model to complete the following tasks in their dissection groups (3-4 students):

- Indicate, by letter and region, which area of the model would be the most likely place to recover remnants of destroyed Schwann cells
- Indicate, (top, middle or bottom), which neuronal fibers most likely represent those from a patient affected by Guillain-Barre Syndrome

- Press each red button (top alpha motor neuron, middle alpha motor neuron and bottom alpha motor neuron) sequentially and indicate which transmits its signal fastest and which transmits its signal slowest
- Indicate, (top, middle or bottom), which spinal cord segment most likely represents electromyography results that would completely rule-out Guillain-Barre Syndrome
- Indicate, by color, which strings represent posterior antebrachial muscles
- Pull on a string representing posterior antebrachial muscles and report the resulting action at the wrist
- Indicate the action created by muscles represented by blue string acting as agonists
- Indicate the action created by muscles represented by yellow string if they were subject to a deep tendon reflex test
- Press the button associated with the dorsal-most (top) upper motor neuron and indicate whether the resulting impulse causes the enlarged muscle model to do nothing, contract or relax
- Press the button associated with the ventral-most (bottom) upper motor neuron and indicate whether the resulting impulse causes the enlarged muscle model to do nothing, contract or relax
- Press the button associated with the first (top) alpha motor neuron and indicate whether the resulting impulse causes the enlarged muscle model to do nothing, contract or relax
- Indicate which button (the dorsal-most upper motor neuron, the ventral-most upper motor neuron, or the first alpha motor neuron) is associated with normal movement

after stimulating muscle/spinal nerve directly, an inability to initiate voluntary movement and a healthy ability to initiate voluntary movement (matching)

- Indicate which symptoms and/or normal results a patient with an upper motor neuron disorder would most likely demonstrate
- Indicate which division of the nervous system upper motor neurons belong to
- Press the ACh molecule into the receptor on the neuromuscular junction box and identify what is released (pressing the ACh molecule into the receptor will release the door on the box and calcium ions will fall out)
- Indicate what clinical symptoms a patient might display if calcium was not actively transported back into the sarcoplasmic reticulum
- Press the tubocurarine molecule into the receptor and identify what is released (the tubocurarine molecule will sit on the push-button receptor, but it will not press it down)
- Identify the first step in the mechanism of skeletal muscle contraction which tubocurarine prevents
- Indicate the result of taking the drug tubocurarine
- Identify, by letter, which portion of the spinal nerve must be affected to cause muscle stiffness and spasms in the upper limb and whether that affect is prolonged stimulation or complete disconnection
- Indicate which neuron types are involved in a reflex arc based on the number of cytoplasmic processes

2.1.6 Control of Electronics

The interaction involving LED lights and pressure sensors were controlled and moderated by ARDUINO® MEGA 2560 microcontroller. Motors and the associated components were controlled and moderated by an ARDUINO® UNO microcontroller. These controller were pre-programed with the appropriate algorithms to facilitate interaction with the model. Algorithms are coded in an ARDUINO-specific coding language with ARDUINO software by an anatomist with extensive training in computer science. The full coded algorithm for both microcontrollers can be seen in Appendix B.

2.2 User Study Design

2.2.1 Timeline

The user studies design for the control group, the activity control group and the intervention group presented the same material and assessments to students at the same time intervals. The main part of the study, (i.e. the duration during which the intervention model was implemented), took place before the first exam in the course. The course was set-up so that students first attended a two-hour laboratory session in the morning (8am, 9am, or 10:20am depending on the section and semester). Following that laboratory session, (20 minutes to an hour afterwards depending on section and semester), students would attend a 50-minute lecture session. This was repeated twice a week (either on Tuesdays and Thursdays or Mondays and Wednesdays depending on the section and semester). The first day of the study (and of the course), after completion of spatial assessments, students were introduced to the laboratory setting and spent additional time with thoracic limb osteology. The first day's lecture introduced the course and covered directional terms. On the second day students received their cadavers and began dissection of the extrinsic muscles of the thoracic limb. In lecture on the second day, students learned the basic tissue types. The third day, and final day before introducing material directly related to the intervention, students completed extrinsic muscles of the thoracic limb and thoracic limb arthrology in the laboratory and covered thoracic limb and general arthrology in lecture. Days four through nine presented and assessed understanding of material directly related to the intervention. Students would first attend a lecture on a topic, (1st - Thoracic Limb Myology and Basic Biomechanics, 2nd – Skeletal Muscle Histology and Physiology, 3rd – The Peripheral Nervous System), followed by a preliminary quiz on that topic. On the next class day, students in the activity control or intervention groups would complete an activity applying the material introduced in the previous day’s lecture. A full 24-hours following the completion of the corresponding activity (activity control and intervention groups only), students took another quiz on the same material. Lecture topics covered 98% functional concepts, however, where structures were referenced or introduced, it was always prior to the dissection of those structures. Each exam topic, (from day one through day eight), was included on the first examination in the course. All lectures, across groups, from day three through the first exam, were designed and delivered in the same way, by the same instructor, for consistency. Figure 37 demonstrates the detailed timeline for the user studies from day one through the first exam.

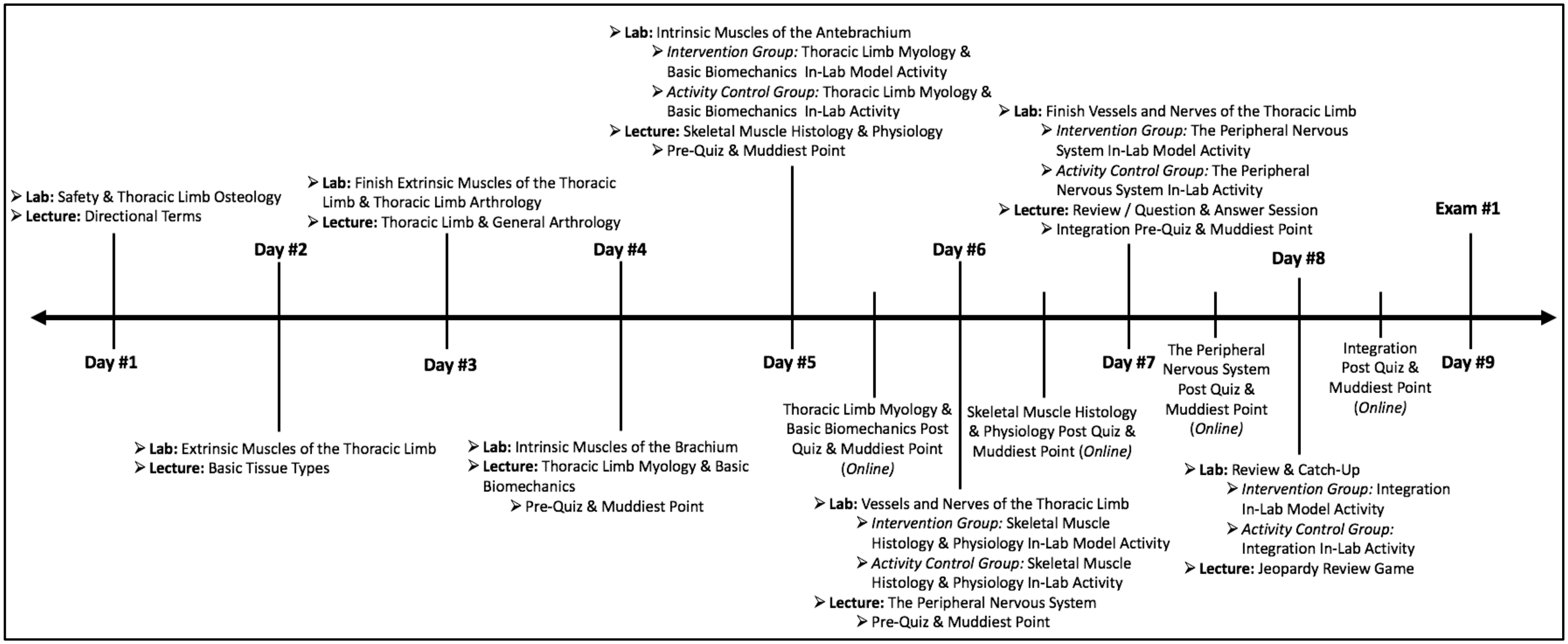

Figure 37: Detailed timeline for user studies from day #1 through the first course exam

2.2.2 Objectives

Objectives for topics covered on each day of the study were carefully designed to align with course-level outcomes as well as all instructional material and assessments.

For efficiency, Benjamin S. Bloom's "Taxonomy of Educational Objectives" (Krathwohl, 2002) was abbreviated into three levels of difficulty (Figure 38):

- Level 1: Remembering
    - This included any questions that required students to find or remember information.
- Level 2: Applying and Understanding
    - This included any questions that required students to use information in a new, but similar, situation and/or understand and make sense out of information.
- Level 3: Creating, Evaluating & Analyzing
    - This included any questions that required students to use information to create something new, critically evaluate information and make judgements, and/or take information apart and explore relationships.

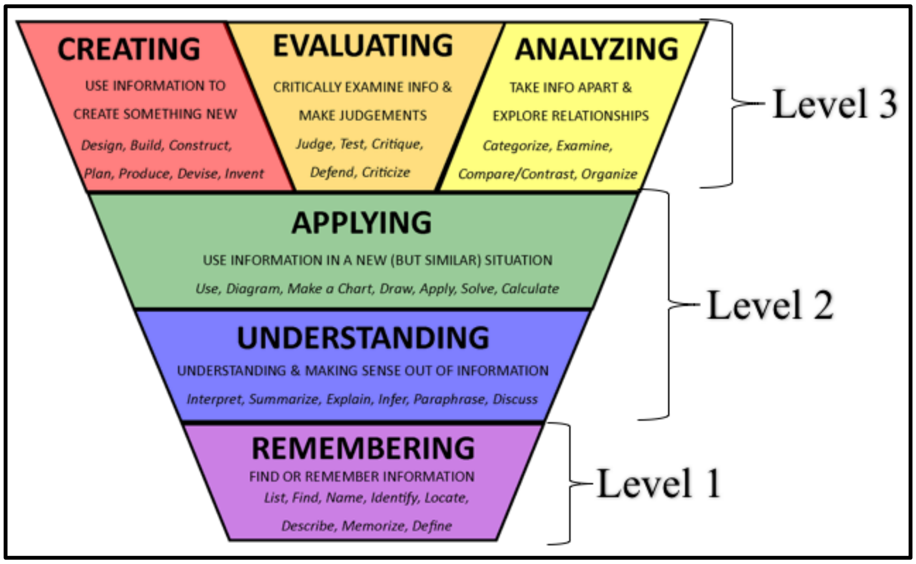

Figure 38: Original Bloom's Taxonomy Objectives (image from https://carleton.ca/viceprovost/blooms-taxonomy/) broken down into three levels of difficulty

2.2.2.1 Course-Level Outcomes

The course-level outcomes (CLO) were pre-determined by the course coordinator.

CLO1: Define and interpret fundamental anatomic nomenclature.

CLO2: Identify and locate normal gross anatomical structures.

CLO3: Relate cellular, tissue, and organ system organization and location to their basic functions.

CLO4: Read an anatomic description and recognize on a cadaver or diagram the described structures.

CLO5: Relate the spatial locations of normal anatomic structures to one another.

CLO6: Compare and contrast the differences and similarities between human and canine gross anatomic structures.

CLO7: Apply anatomic concepts to explain or predict clinical conditions.

2.2.2.2 Objectives by Study Day

For each day of the study, objectives for student learning were carefully outlined for both laboratory sessions and lecture sessions. As the course does not make a separation between lab material and lecture material for assessments, most of these objectives are applicable to both lab and lecture. However, objectives that are structure-based and were not discussed in lecture are identified as "Lab Objectives" in the tables below, objectives for topics directly related to the intervention are also in specific groups according to their topic (Tables 2-8).

Day 1 Lab: Safety & Thoracic Limb Osteology Lecture: Directional Terms								
Objective	Bloom's Level **Difficulty Level**	**CLO1**	**CLO2**	**CLO3**	**CLO4**	**CLO5**	**CLO6**	**CLO7**
Explain relationships among structures using appropriate terminology.	Understand **Level 2**	X	X		X	X	X	
Use the appropriate directional terms to **find** and **describe** structures.	Apply & Remember **Levels 1 & 2**	X	X	X	X		X	
Identify the bones found in each region of the thoracic limb.	Remember **Level 1**	X	X		X	X	X	
Differentiate the bones of the thoracic limb, and **determine** whether it is from the left or right side.	Analyze & Apply **Levels 2 & 3**		X		X	X	X	
Identify the distinguishing features of each of the bones of the thoracic limb and their relevance to other structures.	Remember **Level 1**	X	X		X	X	X	

Table 2: Day 1 topics and objectives, their corresponding Bloom's Taxonomy level and level of difficulty, and the course-level outcomes

Day 2 Lab: Extrinsic Muscles of the Thoracic Limb Lecture: Basic Tissue Types								
Objective	Bloom's Level **Difficulty Level**	**CLO1**	**CLO2**	**CLO3**	**CLO4**	**CLO5**	**CLO6**	**CLO7**
Identify the four basic tissue types and their subtypes.	Remember **Level 1**	X	X	X	X		X	
Relate the main characteristics of each tissue subtype to body location.	Apply **Level 2**		X	X	X		X	
Predict the function of an organ based on predominant tissue subtype.	Evaluate **Level 3**			X	X		X	X
Relate the signs/symptoms of a clinical condition to the specific tissue abnormalities.	Apply **Level 2**			X	X		X	X
Use the terms intrinsic and extrinsic to **describe** muscles of the thoracic limb.	Apply & Remember **Levels 1&2**	X			X	X	X	
Identify the extrinsic muscles of the thoracic limb and **describe** their attachments and actions.	Remember **Level 1**	X	X		X	X	X	

Table 3: Day 2 topics and objectives, their corresponding Bloom's Taxonomy level and level of difficulty, and the course-level outcomes

Day 3 Lab: Finish Extrinsic Muscles of the Thoracic Limb & Thoracic Limb Arthrology Lecture: Thoracic Limb & General Arthrology									
Objective Group	**Objective**	Bloom's Level **Difficulty Level**	**CLO 1**	**CLO 2**	**CLO 3**	**CLO 4**	**CLO 5**	**CLO 6**	**CLO 7**
Three Types of Joints	**Define** the specific components that make up each of the three main structural types of joints, including any accessory structures.	Remember **Level 1**	X		X	X	X	X	
	Compare and Contrast the relevant functional differences among the three structural types of joints.	Evaluate **Level 3**			X			X	X
Synovial Joint Accessory Structures	**Explain** the basic function of the accessory structures associated with synovial joints.	Understand **Level 2**	X			X		X	
Joints of the Thoracic Limb	**Identify** the individual joints of the thoracic limb including their bony and collagenous connective tissue components and clinically relevant features.	Remember **Level 1**	X	X		X	X	X	X
	Predict the instability that would occur if any thoracic limb ligament was ruptured. Be sure to **explain** the instability using proper anatomical terminology.	Evaluate **Level 3**	X		X	X	X	X	X
Lab Objective	**Identify** the major ligaments of the thoracic limb.	Remember **Level 1**	X	X		X	X	X	

Table 4: Day 3 topics and objectives, the group with which they were covered, their corresponding Bloom's Taxonomy level and level of difficulty, and the course-level outcomes

Day 4 Lab: Intrinsic Muscles of the Brachium Lecture: Thoracic Limb Myology & Basic Biomechanics									
Objective Group	**Objective**	Bloom's Level **Difficulty Level**	**CLO 1**	**CLO 2**	**CLO 3**	**CLO 4**	**CLO 5**	**CLO 6**	**CLO 7**
Muscle Descriptors	**Define** the terms origin, insertion, action, tendon, aponeurosis, belly, and head.	Remember **Level 1**	X			X		X	
	Use the above terms to describe three ways that muscle attaches to bone.	Apply **Level 2**	X		X	X		X	
Flexor Angles	**Define** the terms flexor angle and flexor surface.	Remember **Level 1**	X			X		X	
	Determine the location of the flexor angles of joints of the thoracic limb and the relevance to muscle group actions.	Apply **Level 2**		X	X	X	X	X	
Biomechanics	**Define** terms related to biomechanics including agonist, antagonist, synergist, prime mover, and fixator muscles.	Remember **Level 1**	X			X		X	
	Use biomechanical terms to **describe** individual and combined actions of muscles of the thoracic limb.	Apply & Remember **Levels 1&2**	X		X			X	X
Lab Objectives	**Identify** the intrinsic muscles of the brachium and describe their attachments and actions as groups.	Remember **Level 1**	X	X		X	X	X	
	List exceptions to rules within a muscle group.	Remember **Level 1**			X	X	X	X	

Table 5: Day 4 topics and objectives, the group with which they were covered, their corresponding Bloom's Taxonomy level and level of difficulty, and the course-level outcomes

Day 5 Lab: Intrinsic Muscles of the Antebrachium Lecture: Skeletal Muscle Histology & Physiology									
Objective Group	**Objective**	Bloom's Level **Difficulty Level**	**CLO 1**	**CLO 2**	**CLO 3**	**CLO 4**	**CLO 5**	**CLO 6**	**CLO 7**
Tissue Organization	**Diagram** and **label** a cross section of a skeletal muscle including connective tissue layers.	Analyze & Remember **Levels 1&3**	X	X	X	X	X	X	
	List the major functions of connective tissue in skeletal muscle.	Remember **Level 1**			X	X		X	
Muscle Cell Innervation	**Define** the terms recruitment, neuromuscular junction (a.k.a. motor end plate), and motor unit (a.k.a. motor unit ratio).	Remember **Level 1**	X			X		X	
	Explain the "all or none" principle as it applies to skeletal muscle contraction.	Understand **Level 2**			X			X	
Control of Muscle Contraction	**Compare and contrast** the control a given muscle has (i.e. fine vs. course) based on the given motor unit ratios.	Evaluate **Level 3**			X			X	X
	Outline how the force of contraction in skeletal muscle can be regulated.	Analyze **Level 3**	X		X			X	X
Mechanism of Contraction	**Explain** the basic mechanism of contraction (the Sliding Filament Theory) for skeletal muscle including the basic molecular components.	Understand **Level 2**			X			X	X
Lab Objectives	**Identify** the intrinsic muscles of the antebrachium and **describe** their attachments and actions as groups.	Remember **Level 1**	X	X		X	X	X	
	List exceptions to rules within a muscle group.	Remember **Level 1**			X	X	X	X	

Table 6: Day 5 topics and objectives, the group with which they were covered, their corresponding Bloom's Taxonomy level and level of difficulty, and the course-level outcomes

Day 6 Lab: Vessels and Nerves of the Thoracic Limb Lecture: The Peripheral Nervous System									
Objective Group	**Objective**	Bloom's Level **Difficulty Level**	**CLO 1**	**CLO 2**	**CLO 3**	**CLO 4**	**CLO 5**	**CLO 6**	**CLO 7**
Divisions and Terminology	**Describe** the anatomical and functional divisions of the nervous system.	Remember **Level 1**	X			X	X	X	
	Explain afferent, efferent, somatic, and visceral and **determine** which neurons may be associated.	Understand **Level 2**	X			X		X	
Cellular Components	**Describe** the microscopic appearance of neurons and **classify** them based on cellular processes.	Remember **Level 1**	X		X	X	X	X	
	Explain the basic function of Schwan cells.	Understand **Level 2**	X			X	X	X	X
	Determine which neurons are associated with afferent and efferent.	Apply **Level 2**	X			X		X	
The Spinal Nerve	**Diagram** and **label** the somatic components of a spinal nerve.	Analyze & Remember **Levels 1&3**	X	X		X	X	X	
	Predict deficits which would result from damage to specific portions of a spinal nerve.	Evaluate **Level 3**			X	X	X	X	X
Functional Organization Terminology	**Describe** a nerve plexus and **identify** the plexuses associated with the thoracic and pelvic limbs.	Remember **Level 1**	X			X	X	X	
	Define, **compare and contrast** the following terms associated with the nervous system: a) Gray matter d) Nucleus b) White matter e) Tract c) Ganglion f) Nerve	Remember & Evaluate **Levels 1&3**	X		X	X	X	X	

Table 7: Day 6 topics and objectives, the group with which they were covered, their corresponding Bloom's Taxonomy level and level of difficulty, and the course-level outcomes

Day 7 Lab: Finish Vessels and Nerves of the Thoracic Limb Lecture: Review / Question & Answer Session – Integration & Application									
Objective Group	**Objective**	Bloom's Level **Difficulty Level**	**CLO 1**	**CLO 2**	**CLO 3**	**CLO 4**	**CLO 5**	**CLO 6**	**CLO 7**
Lab Objectives	**Identify** the nerves of the brachial plexus and which muscle groups they innervate and **list** exceptions to muscle group innervations.	Remember **Level 1**	X	X		X	X	X	
	Predict motor deficits which would result from damage to any named spinal nerve in the brachial plexus, including damage at different levels of the nerve.	Evaluate **Level 3**	X			X	X	X	X
	Identify the major arteries supplying the thoracic limb including major branches and name changes.	Remember **Level 1**	X	X		X	X	X	
	Predict possible areas of entrapment of a nerve or artery based on its relationship to surrounding structures.	Evaluate **Level 3**				X	X	X	X
Integration Objectives	**Reconstruct** the path of a motor neuron from the spinal cord to the neuromuscular junction **using** knowledge of skeletal muscle organization.	Create & Apply **Levels 2&3**		X	X	X	X	X	
	Predict motor unit ratios for specific muscles of the thoracic limb based on their actions.	Evaluate **Level 3**			X	X		X	X
	Infer the action on a joint when two different muscles contract using individual muscle actions, motor unit ratios, size, and recruitment numbers.	Analyze **Level 3**	X		X		X	X	
	Hypothesize the route of both efferent and afferent impulses from a muscle and/or region of the thoracic limb via the spinal cord and spinal nerves.	Evaluate **Level 3**	X		X	X	X	X	

Table 8: Day 7 topics and objectives, the group with which they were covered, their corresponding Bloom's Taxonomy level and level of difficulty, and the course-level outcomes

2.3 Assessments

The following assessments were administered along the timeline represented below (Figure 39). The box in the timeline represents the full presentation and assessment for a single topic. The events inside of the box were repeated three more times for the three remaining topics before the first exam. Each of the relevant dissections was completed prior to administering the post quiz. It is important to note that the class only met on either Mondays and Wednesdays, or Tuesdays and Thursdays. The days referred to here are to represent the progress of the study, not the amount of time elapsed. Each of these assessments is included in Appendix C.

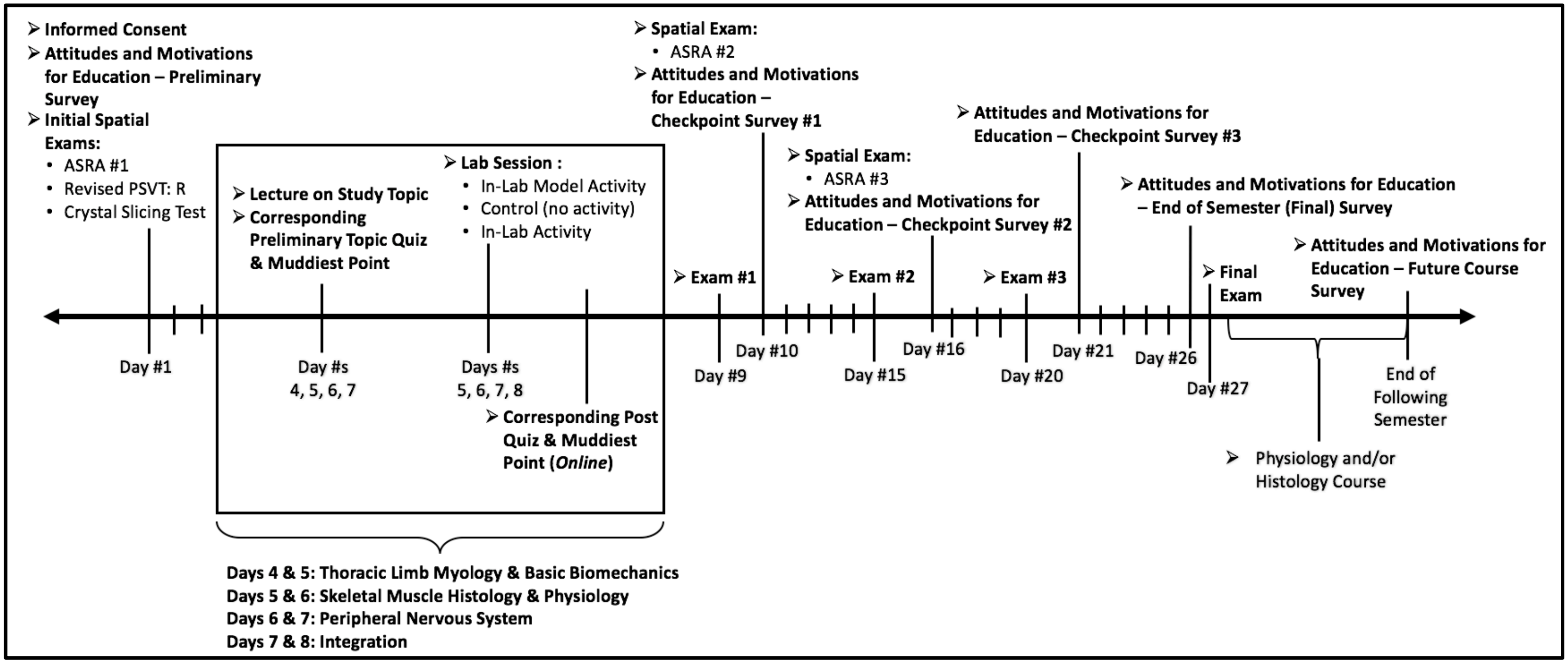

Figure 39: Timeline representing when assessments are administered

2.3.1 Surveys

Survey items were based on previously identified trends for students in the Biomedical Anatomy course, established surveys assessing attitudes and motivations for learning in the life sciences, and surveys used in similar studies (Emerson, 2017; Isaacson, et al, 2016; Lin & McNamara, 1997; Moy, Renshaw & Davids 2016; Walan & Rundgren, 2015; Sad, Goktas & Bayrak, 2014; Sjoberg & Schreiner, 2004).

2.3.1.1 Attitudes and Motivations for Education – Preliminary Survey

The preliminary survey included multiple items designed to reflect the attitudes and motivations of students coming into the Biomedical Anatomy course. This assessment was used to determine the initial attitude of students towards life science courses in general as well as their source and level of motivation to learn the material presented. This survey was also used to gain demographic information about the students in addition to their previous experience with similar life science courses. The survey was given on the first day of class in the lecture section.

Simple distribution analyses were done on demographic information and information pertaining to previous experiences in life science courses. This information was used to assure an appropriate heterogeneity of the sample population. Although beyond the scope of this study, this information could also be used to determine whether any of the variables that are expected to be influenced by the intervention are influenced by demographics or previous experience.

2.3.1.2 Attitudes and Motivations for Education – Checkpoint Surveys

These surveys included two items which are designed to identify how students alter their study methods throughout the course. This assessment also included a ranking of goals used to determine and track any change in attitudes and motivations of the students throughout the semester. Each checkpoint survey was given after the appropriate exam.

2.3.1.3 Attitudes and Motivations for Education – End of Course Survey (Final Survey)

The final survey was administered at the end of the semester for all groups. It is very similar to the preliminary survey and was used to determine students' attitude towards life science courses in general as well as their source and level of motivation following the completion of the Biomedical Anatomy course

2.3.1.4 Attitudes and Motivations for Education – Post Intervention Survey

This survey was only given to the intervention group as it was designed to evaluate the student perceived impact and efficacy of the physically interactive model used as an intervention. The survey was administered following the final post topic quiz and prior to the first exam.

2.3.1.5 Attitudes and Motivations for Education – Future Course Survey

Students typically take the physiology course (VTPP 423: Biomedical Physiology) within two semesters of completing the Biomedical Anatomy course. If students take the Biomedical Anatomy course in the Spring, they may also take the histology course (VIBS 343: Histology) in the Fall following the Biomedical Anatomy course. For this reason, the future course survey was offered to students in the Physiology (Spring and Fall) and the Histology (Fall only) course.

This survey included all the same items as the end-of-course (final) survey and was used to determine students' attitudes toward life science courses in general as well as their source and level of motivation at least one full semester after taking the Biomedical Anatomy course.

Students in half of the control group and the entire intervention were in the Physiology course in the Spring of 2020 when the COVID-19 pandemic began. The second-half, including the conclusion, of the Physiology course was, therefore, completed online. For this reason, the Future Course Survey could not be administered in-person as it was for previous study groups. Instead, all students who took the Biomedical Anatomy course in the Fall of 2019 were sent a link to an online Google Form survey with all the items from the in-person Future Course Survey presented in a slightly different format.

2.3.2 In-Laboratory Observations and Informal Interviews: Student Engagement, Motivation and Critical Thinking Analysis Survey

Due to the large number of students in each of the sections (80 – 96) of Biomedical Anatomy, undergraduate teaching assistants (UGTAs) were utilized as supplemental instructors during laboratory time. Each UGTA was required to have taken the Biomedical Anatomy course within the past two semesters and earned at least a "B" in the course. Students applied for the UGTA position the semester prior to the semester during which they would teach. Their applications were reviewed by previous UGTAs and course instructors and the top candidates were chosen. The UGTAs were concurrently enrolled in a course designed to prepare and guide them in teaching the anatomical sciences (VIBS 489 – Pedagogical Principles and Techniques in Biomedical Anatomy). In the first few classes of this course the UGTAs were taught to recognize different levels of student engagement based on Bloom's

Taxonomy of Educational Objectives (Karthwohl, 2002). Each UGTA was assigned to four specific tables (each table has a group of three to four students and a cadaver) during their corresponding laboratory session. The UGTAs answered questions for the students at these tables and assessed how they were doing in the course based on their conversations. At the conclusion of the final two-hour laboratory session for a given week, each UGTA filled out and turned in one Engagement Analysis survey per table.

This survey assessed engagement based on the observed number of questions students at each table asked and answered and the difficulty level into which those questions were categorized. There was also an area for an open-ended response commenting on the observations concerning the students' engagement, motivation, and/or critical thinking. In addition to lessons on Bloom's Taxonomy and an explanation as to how to fill out the survey, a graphic reminding the UGTAs of these levels and what they included was on each of the surveys.

These surveys and the associated pedagogical training served to standardize the UGTA's interactions with the students.

2.3.3 Spatial Assessments

The assessment of spatial ability in this study is based on the definition and factors outlined by Lohman (1979, 1988). Lohman defined spatial ability as "the ability to generate, retain, and manipulate abstract visual images" (Lohman, 1979). He reported that spatial relations should be assessed with a complex battery of non-verbal tests such as Thurstone's Cards, Flags, and Figures (Thurstone, 1938). These tests typically present an image of a card that has been cut, the image of a flag, or the image of a figure. This image is then shown as it would look rotated to a specific angle. The test taker is then asked to recreate the rotation with a second image provided (Study, 2012). It is also suggested that this factor be tested across a battery of similar tests. Lohman described the spatial orientation factor as involving the ability to determine how an object or surroundings might look from a different perspective. Tests to assess this factor typically have a left-right discrimination and an imagined reorientation in space. Spatial visualization can be assessed in tests such as paper folding, form board, or WAIS Block Design (Lohman, 1979). One of the most important spatial thinking skills that is not described by Lohman is penetrative thinking. This spatial thinking skill is characterized by the ability to visualize spatial relations inside an object, such as is necessary for reading any sort of medical imaging (i.e. MRI or CT imaging) (Ormand et al, 2017). Considering these factors involved in spatial ability, a battery of spatial assessments was compiled and designed to target those spatial skills that are especially relevant to the life-sciences, including anatomy.

The battery of tests used was first piloted with a smaller sample of the same population to be used in the study. Information gathered with this pilot test was used to determine the fitness of the tests for the study as well as to refine the appropriate time and setting for new tests designed specifically for this study. The first spatial assessments (PSVT:R, Crystal Slicing, and ASRA #1) were given on the first day of the class. Other spatial assessments, (ASRA #2 and #3). were given to students following the first and second course exams.

2.3.3.1 Revised Purdue Spatial Visualization Tests: Visualization of Rotations (Revised PSVT:R)

This assessment is a revised version of the Mental Rotation Test from Roland B. Guay. Students are allowed 25 minutes to answer 30 questions designed to assess their ability to visualize the rotation of three-dimensional objects. Each question includes the image of one three-dimensional object from a certain angle, then an image of the same three-dimensional object rotated to a different view. The question then gives a second three-dimensional object and asks the student to decide which of the four choices provided matches the rotated view presented with the first three-dimensional object. Specifically, this test was used to assess the students' skills in spatial relations as described by Lohman (1979). Amongst other studies, this test has been used to measure gender differences in mental rotation ability as well as first year engineering students' spatial ability (Maeda & Yoon, 2012, 2013, 2015).

2.3.3.2 Crystallographic Slicing Test

The Crystallographic or Crystal Slicing Test is a series of 15 questions designed to assess the students' ability to visualize a slice through a given symmetrical three-dimensional solid. Students are allowed only three minutes to answer all of the questions. Each question gives the student a diagram of a symmetrical, solid, crystal shape intersected by a plane and asks the student to determine which of five options matches the shape of the surface that would be made by cutting the crystal along the indicated plane. Specifically, this test was used to assess penetrative thinking as described by Ormand (2017). The Crystal Slicing Test has been used to assess and improve spatial thinking skills in geology students (Gold et al, 2018; Gold et al, 2018; Ormand et al, 2017).

2.3.3.3 Anatomic Spatial Reasons Assessments (Levels 1, 2 and 3)

These assessments were designed by the author alongside experienced anatomists to evaluate the ability of students to recognize relevant anatomical structures in multiple cross-sectional and rotated views. The assessments are organized into three levels of increasing difficulty. Assessments were administered at three different points during the semester and each utilized images from structures that had not yet been covered in the course. The first level (ASRA #1) was administered alongside the PSVT:R & Crystal Slicing and utilized images of the canine pelvic limb. The second (ASRA #2) was administered during the laboratory period following the first exam and utilized images from the human thoracic cavity. Finally, the third (ASRA #3) was administered during the laboratory period following the second exam and utilized images from the human head and neck. Each ASRA included 25 questions which students are given 15 minutes to complete. For a set of four to twelve questions, a cross-sectional diagram was provided and labeled with letters to identify multiple structures. For this set of questions three to four images from different rotational angles (anterior, posterior, lateral, medial, etc.) were also given with a dotted line passing through the image representing the plane at which the cross-sectional diagram was taken. Individual questions consist of an arrow pointing to a structure on the rotational image with a blank which the student was expected to fill with the corresponding letter from the cross-sectional diagram. This test was designed to assess both the spatial orientation factor described by Lohman (1979) as well as penetrative thinking as described by Ormand (2017) within the specific context of the anatomical sciences.

2.3.4 Summative Assessments for Content

A preliminary quiz and a post quiz were administered for each of the following topics:

- Thoracic Limb Myology & Basic Biomechanics
- Skeletal Muscle Histology & Physiology
- The Peripheral Nervous System
- Integration

2.3.4.1 Preliminary Topic Quizzes

Preliminary quizzes were administered immediately following the lecture pertaining to the topic and following the relevant dissection. Students were provided the necessary slides from the lecture presentation at least two days prior to the day the lecture was presented in class. During the lecture, and during a specified time after the presentation, students were allowed to take notes and ask questions. With at least ten minutes left in the class period, students were asked to put away all their notes and the quiz was passed out. At the end of ten minutes, students were required to turn in their quizzes if they have not already done so. The first three quizzes included five multiple-choice questions designed to assess specific objectives presented in lecture. However, the fourth quiz, the integration quiz, included ten multiple-choice questions and a case vignette that students used to answer the questions. Students were allowed twenty minutes for the integration quiz. These quizzes were used to assess the students' initial understanding of the material presented.

2.3.4.2 Post Topic Quizzes

The post quizzes were administered online 24 hours following the laboratory session (and corresponding activity for the intervention and activity control groups) pertaining to the lecture topic. Students were allowed ten minutes to complete five multiple choice questions that were designed to assess the same objectives as were assessed with the pre-quiz. The integration quiz, again, had ten questions and students were allowed twenty minutes to complete this quiz. Questions were presented one at a time and the quizzes automatically closed after the time had run out, even if the student had not completed all the questions. These quizzes were used to assess the students' understanding of the material presented after being given time to study the material with their preferred method and, for the activity control and intervention groups, with methods provided to them in the laboratory sessions.

2.3.4.3 Preliminary and Post Quiz Design

Each preliminary and post quiz was designed to assess the students' ability to meet specific objectives that were made available to them and detailed during the relevant lecture. These are the same objectives outlined previously in section 2.2.2.2 Objectives by Study Day. In the following sections questions are numbered for reference, however in the quizzes given to students, question order was randomized as were answer choices.

2.3.4.3.1 Thoracic Limb Myology and Basic Biomechanics Quizzes

- Question #1:
    - Muscle Descriptors Objectives 1 and 2
    - Question Level: two – Applying: use information in a new (but similar) situation
- Question #2:
    - Flexor Angle Objectives 1 and 2
    - Muscle Descriptors Objective 1
    - Question Level: three – Analyzing: take information apart and explore relationships
- Question #3:
    - Flexor Angle Objectives 1 and 2
    - Question Level: two – Apply: use information in a new (but similar) situation
- Question #4:
    - Biomechanics Objective 1

    - Question Level: two – Apply: use information in a new (but similar) situation
- Question #5:
    - Biomechanics Objectives 1 and 2
    - Question Level: three – Evaluating: critically examine information and make judgements

2.3.4.3.2 Skeletal Muscle Histology and Physiology Quizzes

- Question #1:
    - Tissue Organization Objectives 1 and 2
    - Question Level: two – Applying: use information in a new (but similar) situation
- Question #2:
    - Muscle Cell Innervation Objectives 1 and 2
    - Mechanisms of Contraction Objective 1
    - Question Level: three – Analyzing: take information apart and explore relationships
- Question #3:
    - Control of Muscle Contraction Objectives 1 and 2
    - Question Level: three – Evaluating: critically examine information and make judgements
- Question #4:
    - Mechanism of Contraction Objective 1
    - Question Level: one – Remember: find or remember information
- Question #5:

- Mechanism of Contraction Objective 1
- Lab Objective – Muscles of the Antebrachium
- Question Level: three – Analyzing: take information apart and explore relationships

2.3.4.3.3 The Peripheral Nervous System Quizzes

- Question #1:
  - Divisions and Terminology Objectives 1 and 2
  - Question Level: three – Analyzing: take information apart and explore relationships
- Question #2:
  - Cellular Components Objectives 1 and 2
  - Question Level: three – Evaluating: critically examine information and make judgements
- Question #3:
  - The Spinal Nerve Objectives 1 and 2
  - Question Level: two – Applying: use information in a new (but similar) situation
- Question #4:
  - Functional Organization Terminology Objectives 1 and 2
  - The Spinal Nerve Objective 2
  - Question Level: three – Evaluating: critically examine information and make judgements
- Question #5:

- The Spinal Nerve Objective 1
- Cellular Components Objective 1
- Question Level: one – Remembering: find or remember information

2.3.4.3.4 Integration Quizzes

All of the questions on these quizzes are considered "Level 3", requiring students to do one or more of the following:

- Create – use information to create something new
- Evaluate – critically examine information and make judgements
- Analyze – take information apart and explore relationships.

The primary objective being assessed is listed for each question, however, each question was designed to evaluate the students' ability to integrate and apply information given in the case vignette and/or covered in the class.

- Question #1:
  - The Peripheral Nervous System, Cellular Components Objective 1
- Question #2:
  - Skeletal Muscle Histology and Physiology, Tissue Organization Objectives 1 and 2
- Question #3:
  - The Peripheral Nervous System, The Spinal Nerve Objectives 1 and 2
  - Skeletal Muscle Histology and Physiology, Mechanism of Contraction Objective 1
- Question #4:
  - The Peripheral Nervous System, Cellular Components Objectives 1 and 2

    - The Peripheral Nervous System, Divisions and Terminology Objective 2
- Question #5:
    - Thoracic Limb Myology and Basic Biomechanics, Flexor Angles, Objectives 1 and 2
- Questions #6 and #7:
    - Skeletal Muscle Histology and Physiology, Mechanisms of Contraction, Objective 1
- Question #8
    - Thoracic Limb Myology and Basic Biomechanics, Biomechanics, Objective 2
    - Lab Objective, Muscles of the Antebrachium
- Question #9
    - The Peripheral Nervous System, The Spinal Nerve, Objectives 1 and 2
    - The Peripheral Nervous System, Divisions and Terminology, Objective 1
- Question #10
    - The Peripheral Nervous System, Divisions and Terminology, Objective 1

2.3.4.4 Course Exams

Each regular semester exam in the Biomedical Anatomy course consists of two portions:

- Practical portion comprised of 35 free-response questions (25 identification questions and 10 structure-function correlation questions) administered in the laboratory. To take the practical portion of the exams, students were put into groups according to their section and lab table number. When more than thirty-five students were in a group, rest stops were set up so that each student was stationed at either a question or a rest stop. The students were allowed one minute per question (or rest stop).

- Lecture portion consisting of 25 multiple-choice questions administered in lecture. The lecture exams were administered in the lecture hall where the class met. Students were allowed the full 50-minute lecture period to take the exam.

2.3.4.4.1 Exam #1

Six questions on the lecture portion of the first exam and three questions on the practical portion were written to assess objectives from the lectures presented prior to the topics assessed with preliminary and post quizzes (Directional Terms, Basic Tissues & Arthrology). The remaining 19 questions on the lecture portion and 32 questions on the practical portion were written to assess whether the students met specific objectives presented in lecture and previously assessed with preliminary and post quizzes.

2.3.4.4.2 Exams #2 – Final Exams

Exams two through the final exam each included questions covering objectives from the first exam – a minimum of four questions from the lecture portion and a minimum of two questions from the practical portion.

2.3.5 Formative Assessment Activities

Students in the activity control group were asked to complete a short group assignment during the laboratory session following the relevant lecture. Students were allowed to work with each other, but were not allowed to receive any help from the instructors. This activity allowed students an additional opportunity to practice application of information presented in lecture and to focus their studying. This activity control was used to help determine whether any change or impact to the variables being assessed was strictly due to engagement with the physically interactive model or could be the result of additional, focused, contact time with the material. Students were asked to complete an in-lab activity for each of the following lecture topics:

- Thoracic Limb Muscles & Basic Biomechanics
- Skeletal Muscle Histology & Physiology
- Peripheral Nervous System
- Integration

2.3.6 Formative Assessment Model Activities

These assessments were very similar to the assessments used for the activity control group. However, the in-lab activities for the intervention group required them to engage with the physically interactive model in order to obtain the correct answers. An activity was completed for each of the following lecture topics:

- Thoracic Limb Muscles & Basic Biomechanics
- Skeletal Muscle Histology & Physiology
- Peripheral Nervous System
- Integration

2.4 Statistical Analyses

All statistical analyses were completed using jmp® statistical software from SAS.

Items in the surveys which involved multiple responses or a ranking were used to identify the sample population's self-identified interests and motivations. Each group and survey item was then compared for significant differences and correlations using t-tests, one-way ANOVA, or simple linear regression analyses. Groups were also analyzed and compared according to their spatial ability.

The mean was used to analyze all Likert-scale data overall and frequency distribution of responses (the mode) was used to inform conclusions.

As the robust nature of parametric tests has proven to give reliable results for ordinal data such as Likert-Scale data even when assumptions such as normality are not met, all data underwent parametric testing (Sullivan & Anthony, 2013).

2.4.1 T-Tests

A t-test (Student's Test) was used when two different group means were compared. An alpha level of 0.05 was used to determine significant differences. The type of t-test used was determined based on the nature of the data being analyzed:

- A Paired t-test (t-test for dependent groups, correlated t test) was used to determine if there was a significant difference between preliminary data and post-intervention data (Siegle, 2015).
- An equal variance t-test (Pooled Variance t-test) was used to determine if there was a significant difference between data collected from two different groups with an equal number of people or equal variances between groups (Siegle, 2015).

2.4.2 Analysis of Variances

To control for error, a one-way analysis of variance (ANOVA) was used when more than two independent groups were being analyzed. If a difference between groups was found, a means comparison post hoc test was used to determine which specific groups differed from one another.

2.4.3 Linear Regression

Regression analysis was used to predict the value of the dependent or outcome variable based on the value of an independent or predictor variable. If two or more independent variables needed to be analyzed, multiple regression analysis was used. This type of analysis was only used with continuous (interval or ratio) variables with a linear relationship (determined visually with a scatterplot).

3 POPULATION AND SETTING

3.1 Environment and Population

This study was conducted throughout three semesters of the undergraduate Biomedical Anatomy (VIBS 305) course at Texas A&M University. Students in this course are undergraduates in the Biomedical Sciences Program (BIMS), and are typically in their junior or senior year of undergraduate studies. The majority of the students in this course are preparing to apply to health care professional schools ("Accountability").

The undergraduate BIMS program provides a large population of students accepted to Texas medical, dental and veterinary schools. The following (Figures 40-42) is an overview of the students in this program from 2016 to 2018:

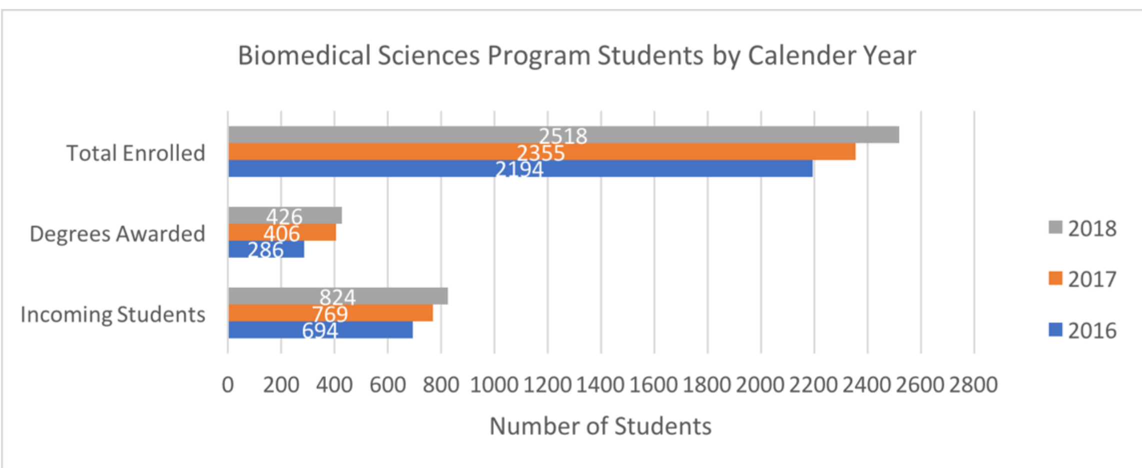

Figure 40: Number of students enrolled, number of degrees awarded, and number of incoming students for the Biomedical Sciences Program, (2016-2018) ("Accountability")

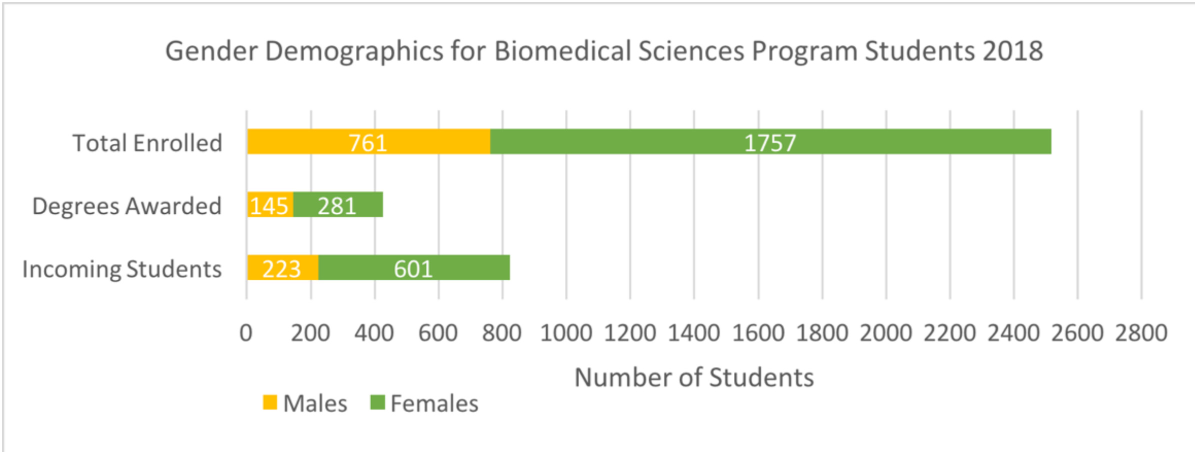

Figure 41: 2018 Gender demographics for students enrolled, number of degrees awarded, and number of incoming students for the Biomedical Sciences Program ("Accountability")

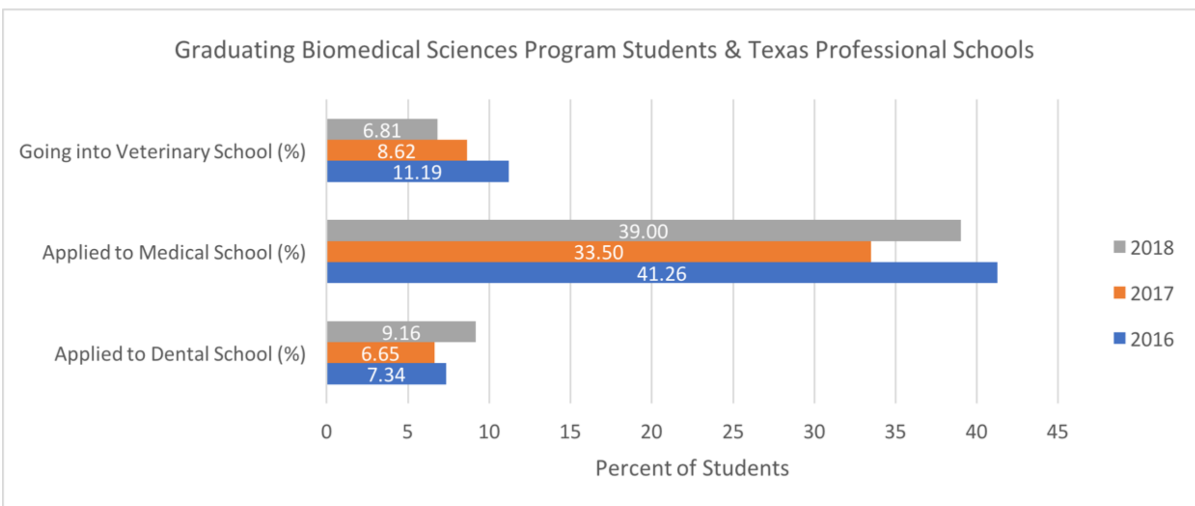

Figure 42: Percent of students from the Biomedical Sciences Program attending or having applied to Texas professional schools (2016-2018) ("Accountability")

3.2 Study Sample Population

3.2.1 Inclusion and Exclusion Criteria

All students within a section of Biomedical Anatomy had the opportunity to participate in the study. Students self-selected for which laboratory section they were enrolled in based on the times offered. All students within a semester were enrolled in the same lecture section. Laboratory meeting times offered during the study included at least one 8am section and one section with a later meeting time (9am or 10:20am) (Table 9). Study groups were assigned to laboratory sections strictly based on the meeting time and semester. Regardless of whether the student gave consent, all assessments were completed by all the students in the class as part of their grade and participation in the course. However, only those scores and responses belonging to students who returned a signed written consent on the first day of class were used in analyses. Data collected from students who were repeating Biomedical Anatomy were also excluded from the analysis. [IRB2018-0771M]

Group	Control		Activity Control	Intervention
Semester	Fall 2018	Fall 2019	Spring 2019	Fall 2019
Laboratory Section Meeting Time	9am	8am	1x 8am 1x 10:20am	1x 8am 1x 10:20am

Table 9: Distribution of study groups across semesters and laboratory section meeting times

3.2.2 Study Sample Demographics

Of the 576 students who were originally enrolled throughout the three semesters during which this study was conducted, 461 provided signed consent forms (80.03%). Participation in the study was offered to 192 students for each of the study groups. Of those students, 172 participated (provided consent) in the control group (89.58%), 117 in the activity control group (60.94%) and 172 in the intervention group (89.58%).

All three sample populations aligned well with overall population data for Biomedical Sciences students. On average, students were between 20 and 21 years of age and mostly seniors in their undergraduate career at the time they took the Biomedical Anatomy course. The preliminary survey only asked students to list their class year. As it is not possible to determine which semester during that year the students plan to graduate, information was gathered from "howdy.tamu.edu", Texas A and M's main intranet website for faculty and students, to determine which stage of their undergraduate career each student was in at the time of the Biomedical Anatomy course. All study samples were also overwhelmingly female. The average self-reported grade point average (GPA) across all groups was 3.53, with averages of individual study groups only varying slightly. In the entire study population, as well as in each study sample individually, less than half of the students had taken a previous anatomy course (Table 10).

Of those who had taken a previous anatomy course, only 172 out of the entire study population reported that their previous anatomy course included a dissection. When asked what species was dissected, "cat" was the most common response, but all of the following species appeared at least once for each of the study samples:

- Cat
- Sheep heart

- Cow eye
- Rat
- Frog
- Pig
- Sheep brain
- Fetal pig

Demographic Data by Sample Population												
Sample	Percent Consenting	Number Consenting	Number Providing Demographic Data	Average Age	Males	Females	Juniors	Seniors	Graduate Students	Number Providing GPA Data	Self-Reported GPA Average	Number with Previous Anatomy Course
Entire Population	80.03%	461	444	20.86	110	334	12	448	1	415	3.53	200
Control Group	89.58%	172	167	20.99	40	127	3	169	0	155	3.57	78
Activity Control Group	60.94%	117	111	20.64	28	83	7	110	0	107	3.46	50
Intervention Group	89.58%	172	166	20.87	42	124	2	169	1	153	3.54	72

Table 10: Basic distribution statistics on demographic data for sample population

3.2.3 Study Setting

This study took place at Texas A and M University, College of Veterinary Medicine and Biomedical Sciences. The Biomedical Anatomy course in which the intervention was used is overseen by the Department of Veterinary Integrative Biosciences and the course is a degree requirement for students in the Biomedical Sciences Bachelor's Program.

The Gross Anatomy Teaching Laboratory at Texas A and M University consists of a small dissection laboratory room with eight tables and a large dissection laboratory room with 30 tables. For this study, 24 of the 30 tables in the large laboratory room were assigned one canine cadaver and four undergraduate students each. Six to seven UGTAs (undergraduate teaching assistants), at least one faculty instructor and at least two graduate teaching assistants were assigned to each section of the Biomedical Anatomy course. The following portions of the study took place in the Gross Anatomy Teaching Laboratory:

- Spatial testing
- In-lab quizzes
- Model activities
- Control activities
- Observations/Evaluations
- Post intervention survey
- Practical portions of course exams

The room used for the lecture portion of the Biomedical Anatomy course varied based on the number of students and the number of sections offered each semester. However, all rooms were equipped with internet access, a microphone, computer, and overhead projector necessary to present traditional lectures. The following portions of the study took place in the lecture classroom:

- Lectures
- Pre-Quizzes & Muddiest Points
- All other surveys

Due to the amount of material that must be covered in the course and the restricted amount of class time, post quizzes and the associated muddiest points were administered online using the eCampus platform.

4 HYPOTHESES AND OUTCOMES

The following hypotheses and outcomes indicate the purpose of this study, expected results, measures used to obtain those results, and the justification for the expectations.

4.1 Hypothesis #1: Attitudes Towards Learning

Engaging with a physically interactive model will have a positive and sustained influence on students' attitudes towards learning, including their source of motivation (i.e. internal vs. external).

4.1.1 Research Outcomes

- To determine the extent to which supplemental instruction with a physically interactive model will affect students' attitude toward learning life sciences.
    - To determine whether this effect is positive or negative.
    - To determine whether any change in students' attitudes towards learning after engaging with a physically interactive model is retained throughout the remainder of the students' undergraduate career.
- To determine the extent to which providing alternative methods and approaches to material in life sciences will affect students' source of motivation.
    - To determine whether this effect is positive or negative
    - To determine whether any change in students' source of motivation after engaging with a physically interactive model is retained throughout the remainder of the students' undergraduate career.

4.1.2 Classroom Level Outcomes

- To influence a significant and sustained improvement in students' attitude toward learning life sciences using supplemental instruction with a physically interactive model.
- To influence a significant and sustained shift toward internal motivation regarding learning the life sciences using supplemental instruction with a physically interactive model.

4.1.3 Hypothesis Specific Assessments

- Attitudes and Motivations for Education – Preliminary Survey
- Post Intervention Survey
- Attitudes and Motivations for Education - Checkpoint Surveys
- Attitudes and Motivations for Education – End of Course (Final) Survey
- Attitudes and Motivations for Education - Future Course Survey

4.2 Hypothesis #2: Study Habits

Engaging with a physically interactive model will have a positive & sustained influence on students' study habits.

4.2.1 Research Outcome

To determine the extent to which supplemental instruction with a physically interactive model will affect study habits adopted by students studying for the life sciences.

- To determine whether this affect is positive or negative.
- To determine whether any change in students' study habits after engaging with a physically interactive model is retained throughout the remainder of the students' undergraduate career.

4.2.2 Classroom Level Outcome

To influence a significant and sustained improvement in the efficiency of study methods adopted by students for learning the life sciences.

4.2.3 Hypothesis Specific Assessments

- Attitudes and Motivations for Education – Preliminary Survey
- Attitudes and Motivations for Education - Checkpoint Surveys
- Attitudes and Motivations for Education – End of Course (Final) Survey
- Attitudes and Motivations for Education - Future Course Survey

4.3 Hypothesis #3: Academic Performance

Engaging with a physically interactive model will have a positive and sustained influence on students' academic performance in life science courses. This influence will be greater and more positive for students with high to intermediate spatial ability.

4.3.1 Research Outcome

To determine extent to which supplemental instruction with a physically interactive model will affect students' academic performance in life science courses.

- To determine whether this affect is positive or negative.
- To determine whether this affect is influenced by spatial abilities.

4.3.2 Classroom Level Outcome

To influence a significant and sustained improvement in students' academic performance in life science courses using supplemental instruction with a physically interactive model.

4.3.3 Hypothesis Specific Assessments

- Preliminary Quizzes

- Post Quizzes
- Course Exam Scores
- Spatial Assessments

4.4 Expectations for Outcomes

Self-reported answers to in-class reflection questions reveal that students coming into Biomedical Anatomy tend to find the course intimidating due to the amount of material covered and the amount of time required to do well in the course. As in many other life science courses, the students see the course as an obstacle which they must overcome and conquer in order to reach their goal of admission into professional school. Their motivation to do well in the course comes primarily from the will to get good scores so that their transcripts and GPA are competitive when applying to professional schools (Anderton, Chiu & Aulfrey, 2016; Eleaser & Kelso, 2018). Instructors have observed that students coming into Biomedical Anatomy are rarely primarily motivated by intrinsic factors such as personal curiosity or challenge. Encouraging students to construct their own thorough understanding of difficult concepts by engaging with an interactive, visual, and tactile representation of gross and microscopic functions previously left to the imagination could make learning these concepts more accessible for many students (Anderton, Chiu & Aulfrey, 2016; Eleaser & Kelso, 2018; Orsini et al, 2015). If even difficult concepts are considered more attainable for students, their attitudes towards learning life sciences could be significantly improved. With positive attitudes and less perceived intimidation, students may be more comfortable asking questions and challenging themselves, leading to a shift towards internal motivation in learning that is sustained throughout their educational career (Liu, Hau & Zheng, 2019; Orsini et al, 2015). Once students interact with this model, they may realize that study methods outside of rote memorization, reading and rewriting notes are more suitable to their learning style for some concepts (Husmann & O'Loughlin, 2019; Quinn et al, 2018). With this realization and intrinsic motivational factors driving their studying outside of class, students may be more likely to adopt study habits that are more efficient (Cross et al, 2019). With more efficient study habits, internal motivation and a positive attitude towards learning, students should be better able to understand and apply the material, which should then impact in their academic performance in the course (Anderton, Chiu & Aulfrey, 2016; Cross et al, 2019; Eleaser & Kelso, 2018; Liu, Hau & Zheng, 2019; Orsini et al, 2015).

5 RESULTS

5.1 Surveys

All survey data was translated into numerical data. When responses ranged from strongly agree to strongly disagree, strongly agree was translated to the number 5, agree to 4, undecided to 3, disagree to 2, and strongly disagree to 1. Responses ranging from very important to not important, very important was translated to the number 5, important to 4, undecided to 3, somewhat important to 2, and not important to 1. Finally, when responses ranged from very often to never, very often was translated to the number 5, often to 4, undecided to 3, sometimes to 2, and never to 1.

5.1.1 Attitudes and Motivations for Education – Preliminary Survey

Evaluation of the preliminary survey results revealed many trends within the study population.

Future career goals for students within the study population reflected the trends within the larger population of students in the Biomedical Sciences undergraduate program. Within the entire study population, as well as within each study group, the majority of students planned to apply to medical school. The second largest group of students was consistently pre-veterinary medicine, followed by future careers as either dentists or physician assistants. Although most students chose future career goals listed on the survey (and in the graph below), other students listed health care professions such as optometry, chiropractic, pharmaceutical sales, and occupational therapist. Interestingly, other students listed professions unrelated to health care such as financial planning, law school, chemical engineering, and conservation ecology. A summary of responses for future career goals amongst the study population is represented in figure 43. Students who chose more than one option for career goals were excluded from these data.

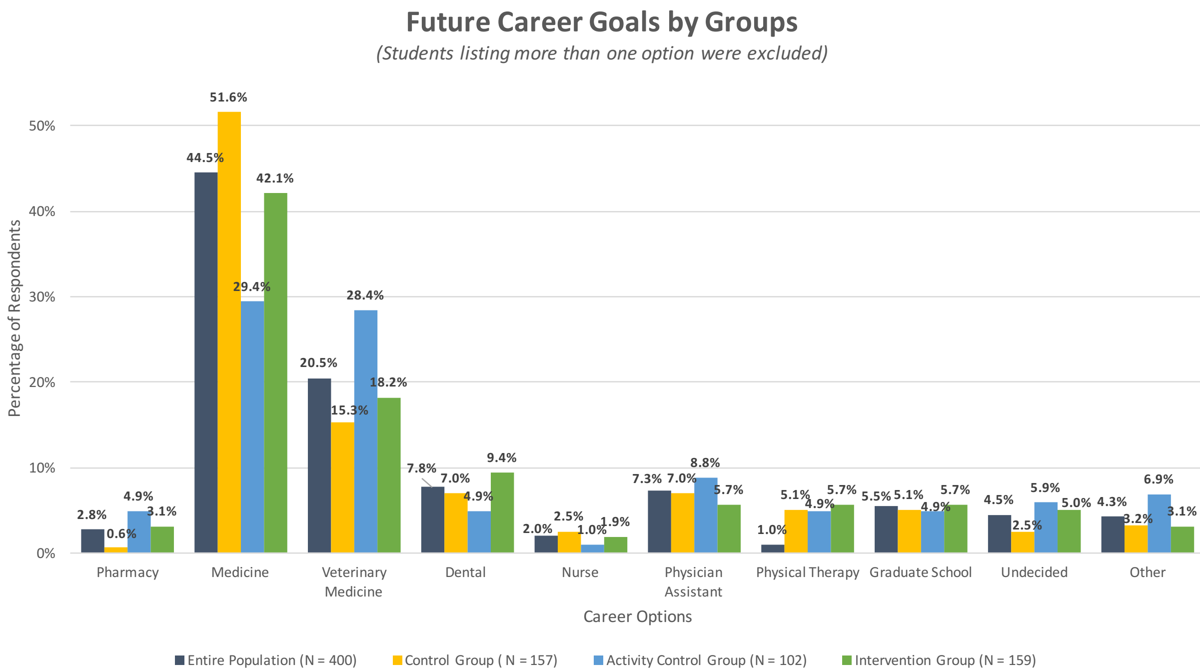

Figure 43: Future career goals by groups

The hobbies that students listed were also informative in regard to their interests and passions. These hobbies were grouped by common traits including media consumption, physical activity, or creating new things, with learning standing as its own group. While most students chose options in each group, a large majority of students chose hobbies involved in media consumption or physical activity. Many students listed “reading” as an “other” option, and it is therefore represented in the graph below (Figure 44). Other hobbies that students listed in addition to the hobbies listed on the survey (and in the graph below) included hobbies involving music, traveling, spending time with others, fishing, activities involving animals, hiking, baking, and puzzles. It is important to note that students were asked to choose all hobbies that applied to them. Most students chose more than one option.

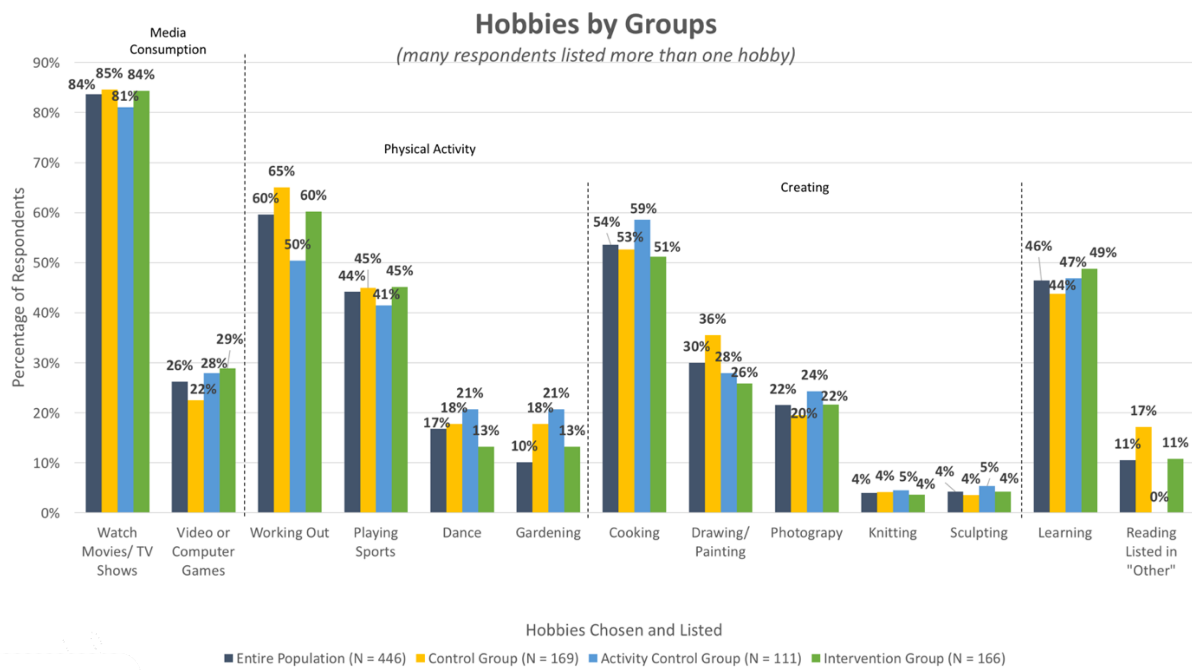

Figure 44: Hobbies by group

Survey items which were designed to evaluate the approaches and attitudes of students to academics in general varied significantly amongst groups. Although the modes for the control, activity control and intervention groups (4, 4.5 and 4 respectively) were similar, the average response from activity control group's surveys indicated that their study plan for the Biomedical Anatomy course was no different from previous life science courses. This was significantly different from the mean response from both the control group ($p < 0.0001$) and the intervention group ($p < 0.0001$). Mean responses for the activity control group also indicate that they did not enjoy studying for life sciences courses more than studying for other courses (mode = 2). Again, this was significantly different than the control group (mode = 4, $p < 0.0001$) and the intervention group (mode = 4, $p < 0.0001$). Responses to both items about learning in general and learning life science also indicated that students in the activity control group were significantly lower than the control ($p < 0.0001$ for both items) and activity control ($p < 0.0001$ for both items) groups. This difference, however, was only observed with the mean scores as the mode for item "In general, I enjoy learning" for all three groups was 4 and the mode for item "I enjoy learning life science more than other topics" was 5 for both the control and activity control group and 4 for the intervention group. The "I learn the most in courses that challenge me the most" item for the activity control group also had a significantly lower mean response than the control ($p < 0.0001$) and intervention ($p < 0.0001$) groups. However, the mode scores were the same (mode = 4) for all three groups on this item. In contrast, the activity control group's mean response indicated that they believed they learned significantly more from memorization over application than the control ($p = 0.0002$) and the intervention group ($p = 0.0006$). Although, the mode for this item was again the same for all three groups (mode = 2). All three groups did agree (mode = 4) that they enjoyed studying in general. The groups were also united in their responses to "The most challenging courses are the most enjoyable" (mode =3). Mean responses for "When preparing for a test, I prefer to memorize information rather than practice application" were not significantly different amongst groups, but the mode for the control group and the intervention group indicated that they disagreed with the statement whereas the mode for the activity control group indicated that they were undecided. These results are summarized in figure 45 below.

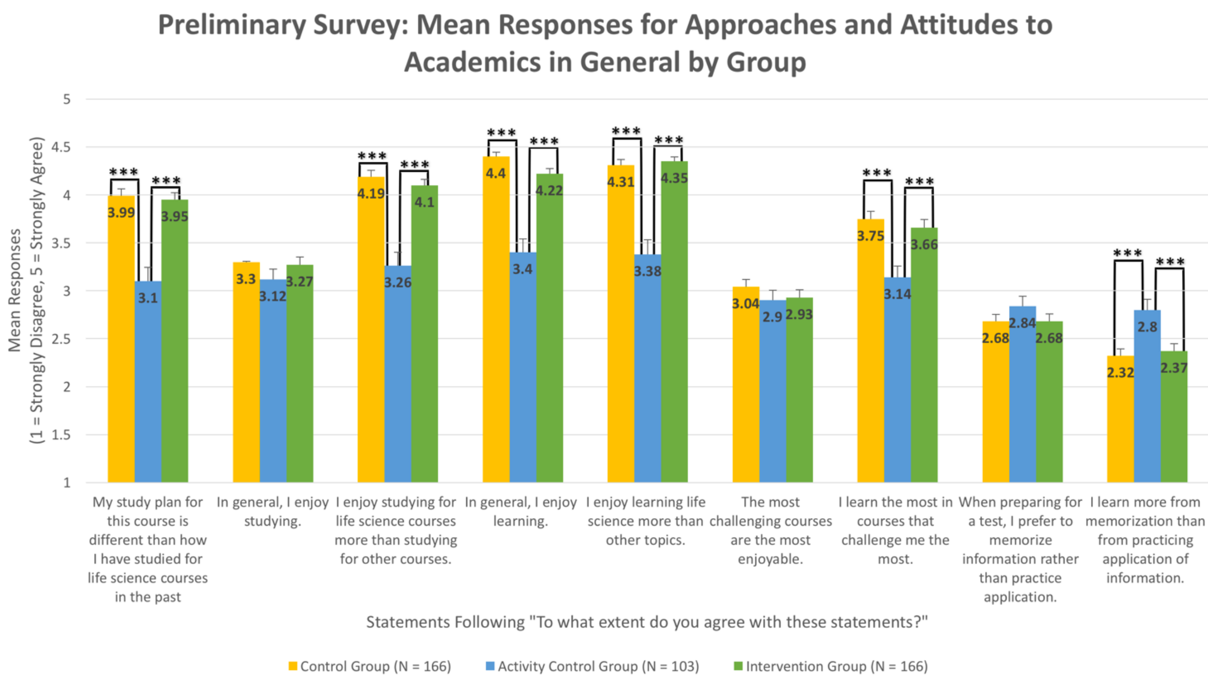

Figure 45: Mean responses for approaches and attitudes to academics in general by group for the preliminary survey with error bars for the standard error of the mean

Only two of the nineteen items designed to evaluate personal significance of various aspects of future careers differed significantly amongst mean responses for groups on the preliminary survey. Similar to results found in the mean responses for approaches and attitudes to academics in general above, the activity control group's mean response for the item "Helping other people" was significantly lower than both the control ($p = 0.0018$) and the intervention ($p = 0.0232$) groups. However, the mode for all three groups on this item was a 5, or "strongly agree". Interestingly, the mode responses amongst groups (control group = 4, activity control group = 5 and intervention group = 1) for the item "Working with animals", seemed to indicate a difference, however the mean responses did not differ significantly. A similar difference among measurements of the survey responses was also seen with the items "Working artistically", (modes: control group = 2, activity control group = 4 and intervention group = 2) and “Making, designing, or inventing new things”, (modes: control group = 2, activity control group = 4 and intervention control group = 4). However, both measurements of mean and mode for item “Becoming or being the boss” differed, although indicating slightly different relationships amongst groups. Mean responses for this item indicate that the intervention’s mean response was significantly lower than that of the control ($p = 0.0107$) and intervention ($p = 0.0048$) groups. The mode responses for this item in the intervention group and the activity control group was a 2, or “disagree”, while the control group’s mode response was a 4, or “agree”. Mean responses for the item “Working as part of a team”, again showed a significantly lower response for the activity control group when compared with the control ($p = 0.0003$) and intervention ($p = 0.0365$) groups. The modes for this item only differed slightly (control = 5, activity control and intervention = 4). The mean responses for all groups and items for this portion of the preliminary survey can be seen on the graph in figure 46.

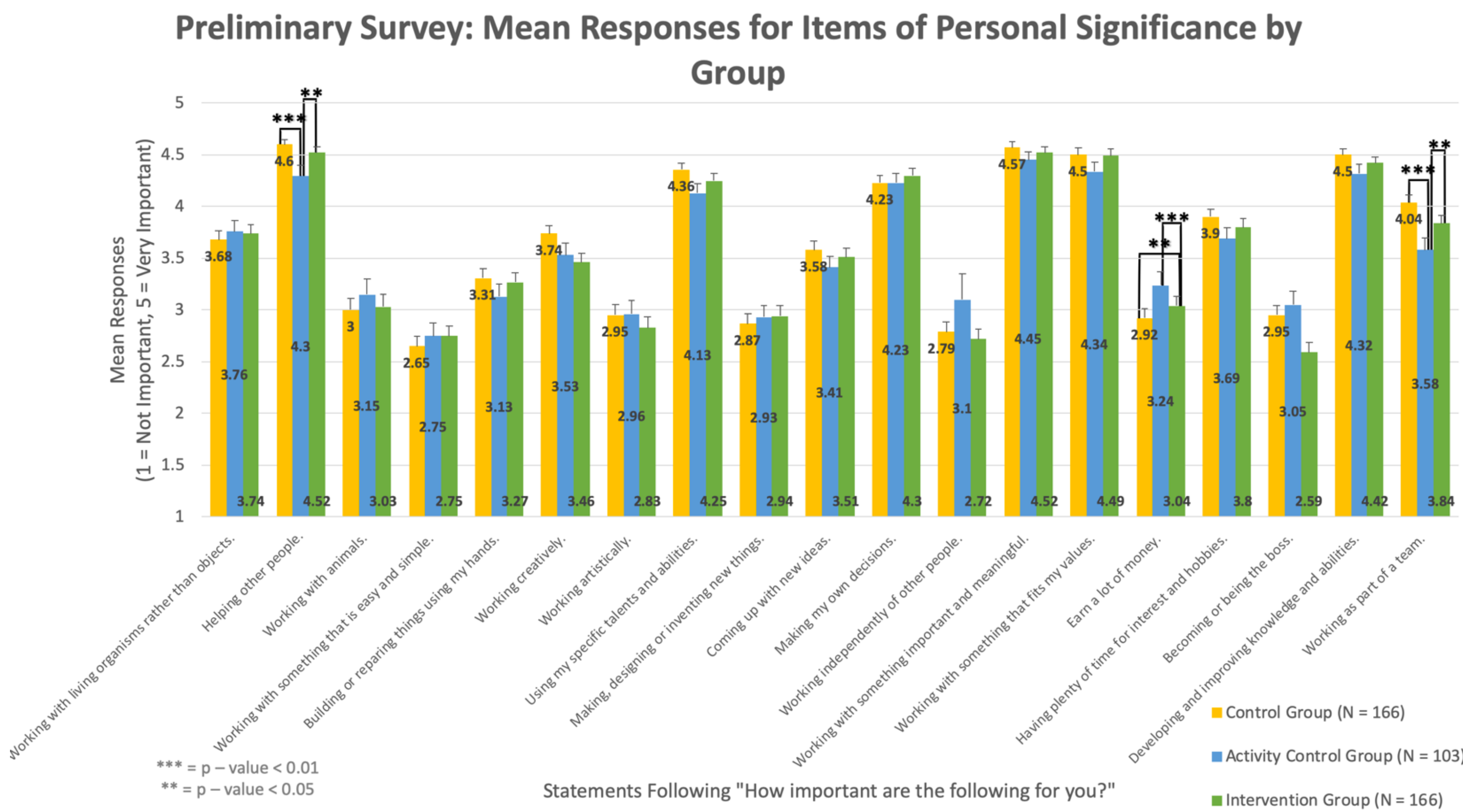

Figure 46: Mean responses for items of personal significance by group for the preliminary survey with error bars for the standard error of the mean

Mean responses for items related to life science courses' impact show that the activity control group perceived life science courses to be consistently and significantly lower in impact compared to the control (all p <0.0001) (Figure 47). However, mode responses indicate that all groups either "agreed" or "strongly agreed" with this statement.

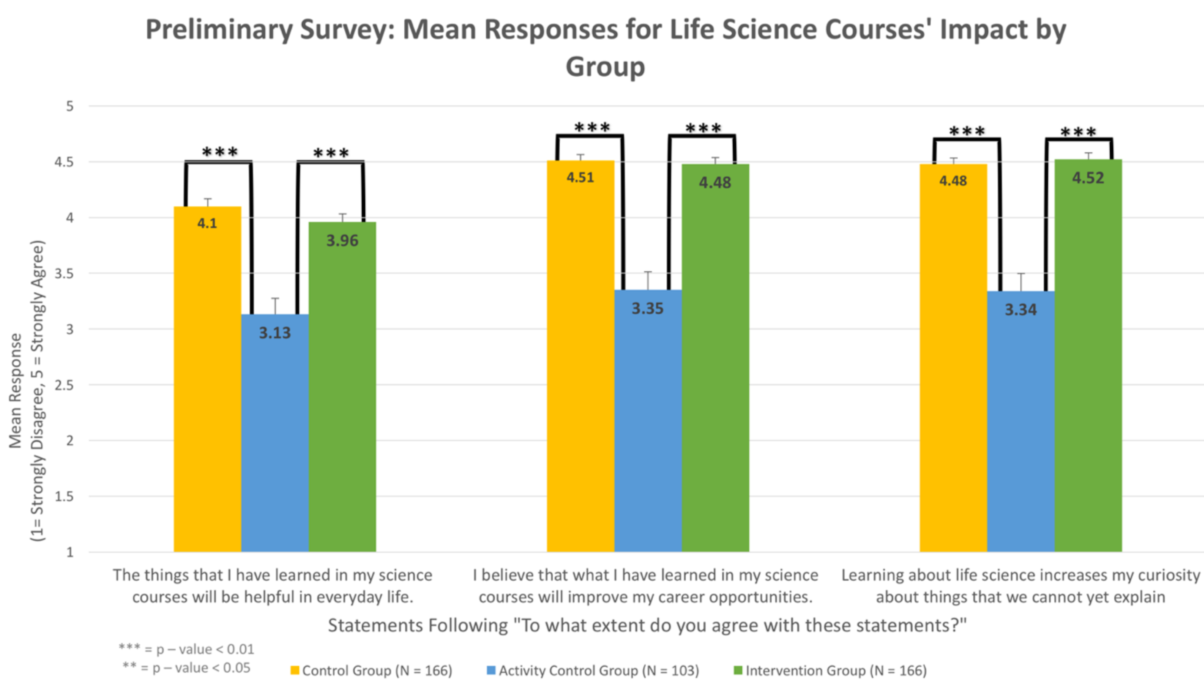

Figure 47: Mean responses for life science courses' impact by group for the preliminary survey with error bars for the standard error of the mean

Responses for items designed to evaluate students' interest in nature and/or sciences outside of the classroom did not differ significantly amongst groups, but were consistently low (Figure 48).

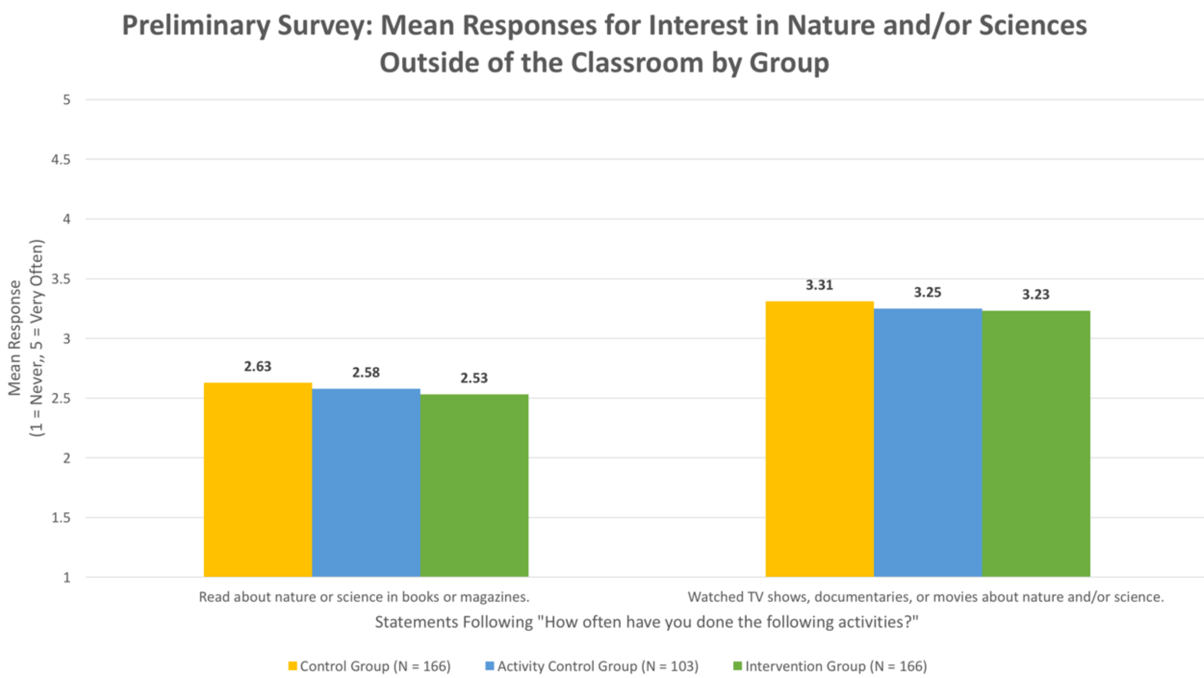

Figure 48: Mean responses for interest in nature and/or sciences outside of the classroom by group for the preliminary survey

5.1.2 Attitudes and Motivations for Education – Checkpoint Surveys

The first and third checkpoint surveys did not indicate any significant differences amongst group responses, however, the item "My study method for this past exam was significantly different from previous exams in this course" for the second checkpoint survey did differ significantly (activity control to control $p < 0.0001$, activity control to intervention $p = 0.0024$ and control to intervention $p = 0.002$) (Figures 49-51). Modes for this item were also different with a mode of 4, or "agree" for the activity and intervention groups, and a mode of 2, or "disagree" for the control group.

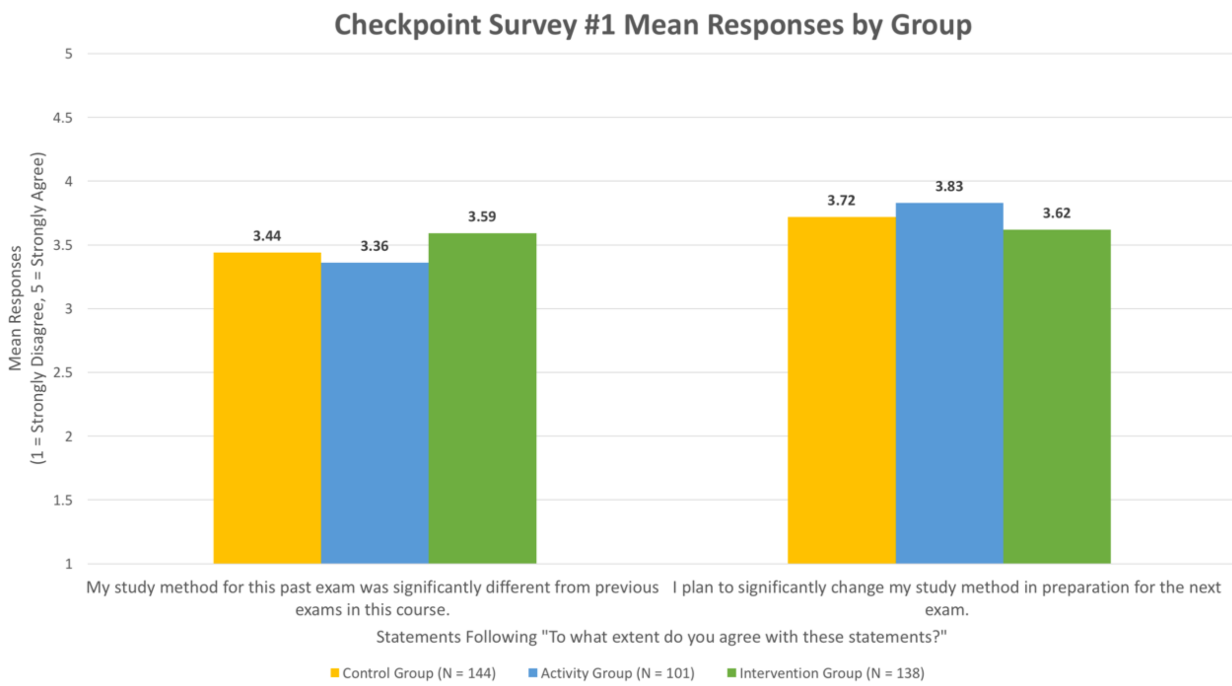

Figure 49: Mean responses for checkpoint survey #1 by group

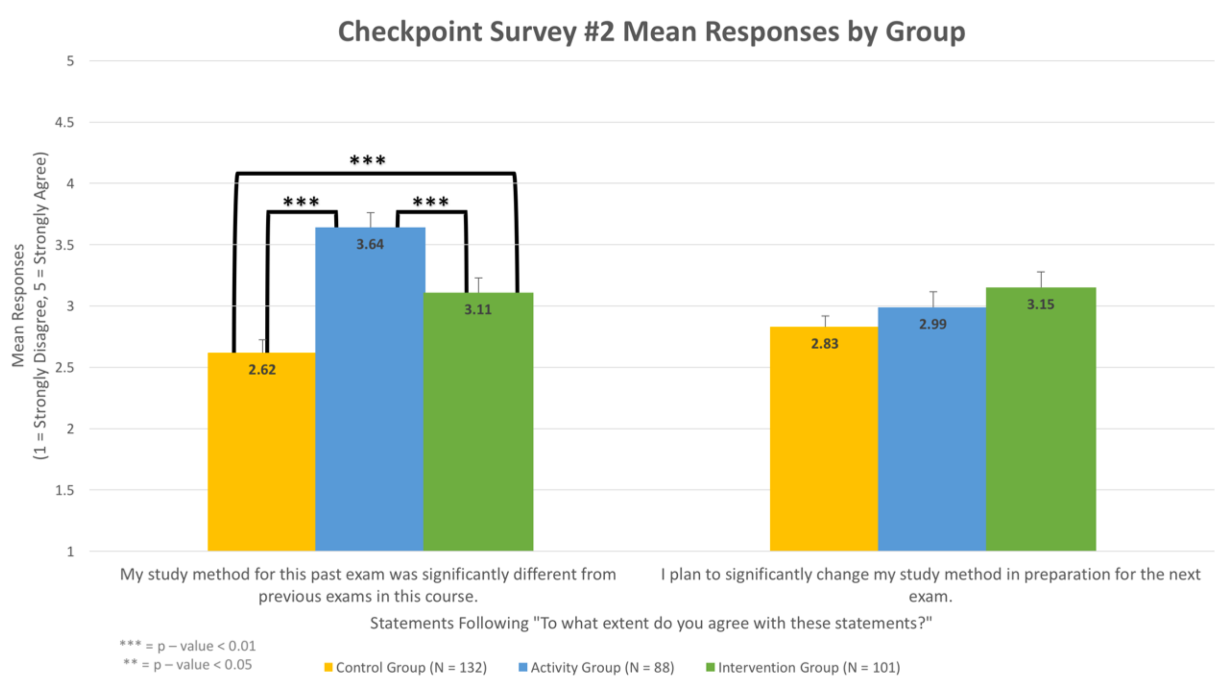

Figure 50: Mean responses for checkpoint survey #2 by group with error bars for the standard error of the mean

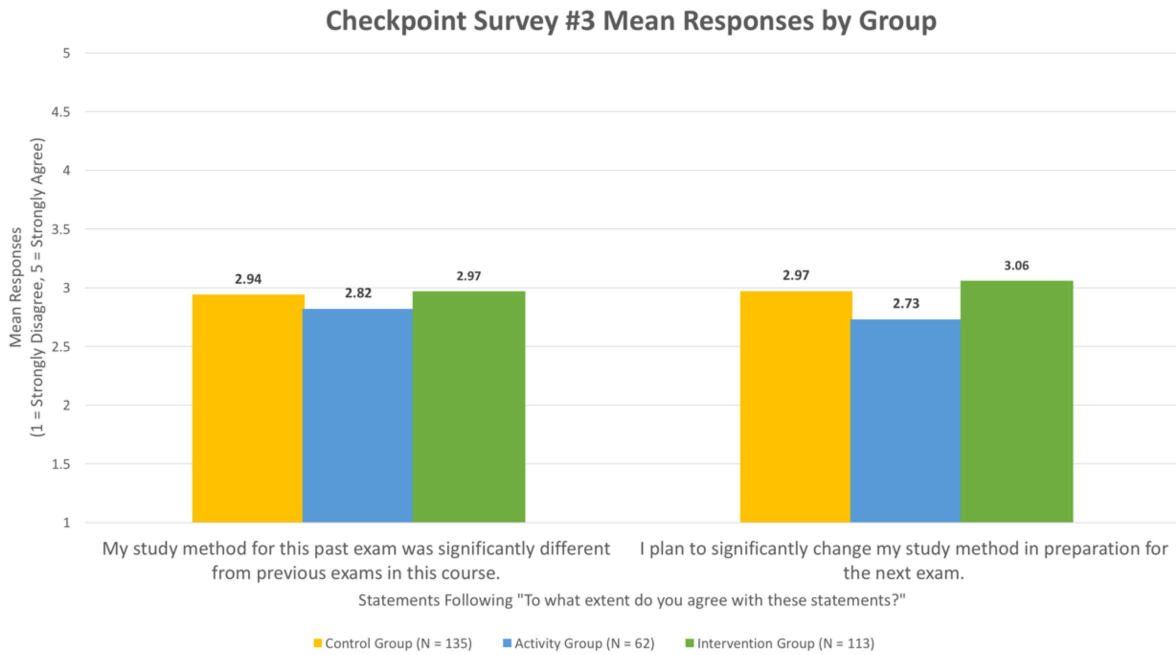

Figure 51: Mean responses for checkpoint survey #3 by group

Mean responses for the checkpoint surveys also indicate that each group changed their method for studying, or planned to do so, significantly at one or more points throughout the course.

The control group started off (checkpoint survey #1) with a significantly higher instance of different study methods for the first exam (checkpoint #2 $p < 0.0001$ and checkpoint #3 $p = 0.0002$), and seemed content with the method, using it again for the second exam (checkpoint #2). However, students did not stick with this method for the third exam, as the third checkpoint survey, taken directly after the third exam, did show a significantly higher instance of different study methods ($p = 0.017$). This same group, however, indicated that they planned to change their study methods after the first exam (checkpoint #2 and #3 $p < 0.0001$)

significantly more than they felt was necessary after the second and third exams. These changes are represented graphically in figure 52 below.

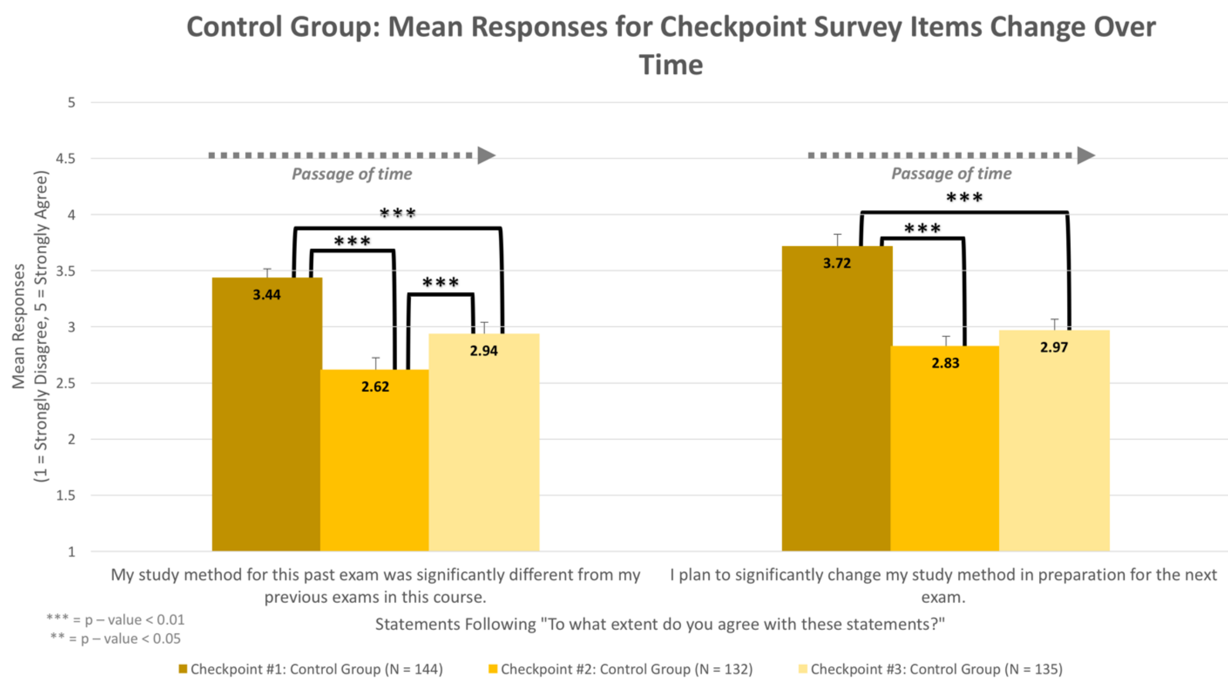

Figure 52: Change over time in mean responses within the control group for items on the checkpoint surveys with error bars for the standard error of the mean

The activity control group also started off (checkpoint #1) with a significantly higher instance of different study methods for the first exam compared to the same instance for the third exam (checkpoint #3) (p = 0.0016). However, students reported that their study methods for the second exam did change (checkpoint #2) significantly more than their methods changed for the third exam (checkpoint #3) (p <0.0001). Similar to the control group, students in the activity control group reported that they planned to change their study methods after the first exam (checkpoint #2 and #3 p <0.0001) significantly more than after the second and third exams. These changes are represented graphically in figure 53 below.

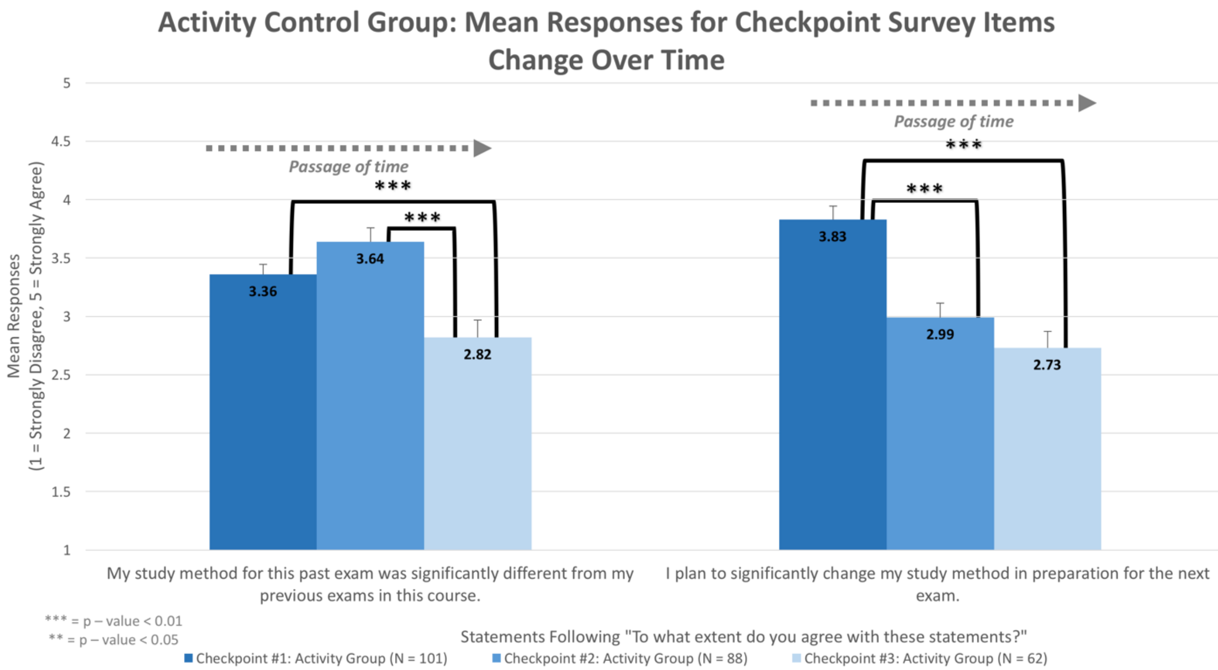

Figure 53: Change over time in mean responses within the activity control group for items on the checkpoint surveys with error bars for the standard error of the mean

Like the control and activity control groups, the intervention group approached the first exam with a significantly higher instance of different study methods than were reported for both the second exam (checkpoint #2 p = 0.0012) and the third exam (checkpoint #3 p <0.0001). Again paralleling the results from the other two groups, the intervention group reported that they also planned to change their study methods after the first exam (checkpoint #2 p = 0.0071 and checkpoint #3 p = 0.0008) significantly more than after the second and third exam. These changes are represented graphically in figure 54 below.

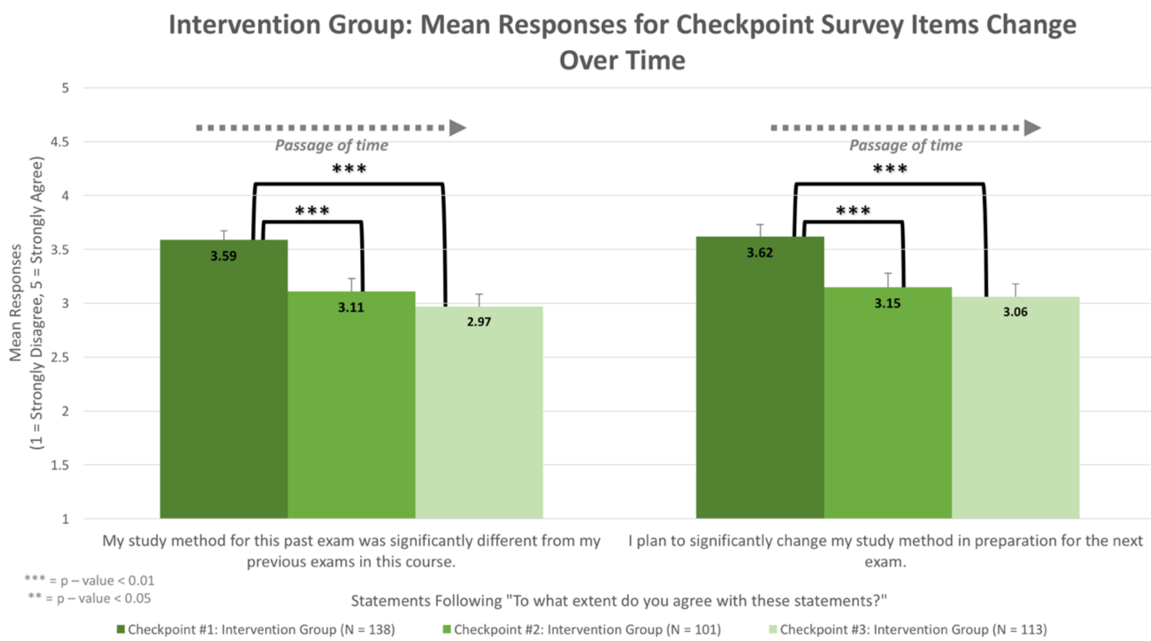

Figure 54: Change over time in mean responses within the intervention group for items on the checkpoint surveys with error bars for the standard error of the mean

5.1.3 Attitudes and Motivations for Education – End of Course Survey (Final Survey)

Items included on the end of course survey (titled "Final Survey" in the Appendix), were designed to evaluate the students' approaches and attitudes to the course as a reflection on the past semester as well as a reevaluation of some of the same items from the preliminary survey.

While the mean responses for most of the items designed to evaluate the students' approaches and attitudes to academics were similar amongst groups, mean responses from three items did differ significantly. Students' perceived enjoyment from practicing application and thinking critically was significantly lower from the control group to the intervention group ($p = 0.006$) and from the activity control group to the intervention group ($p = 0.0407$). Mean responses for students in the activity group indicate that the value they placed on the information they learned in the course was significantly higher than the value students in the intervention group placed on the same information (p = 0.0119). However, the mode responses for all three groups indicated that students "strongly agreed" that they would be able to use the information from the course in their futures. In a similar instance, the mode responses for the item "I learn more from memorization than from practicing application of information" indicate that all three groups disagreed with the statement. However, mean responses indicate that the intervention group did perceive to learn significantly more from memorization than application of information than both the control (p = 0.0207) and the activity control (p = 0.0087) groups. The mean responses for items evaluating students' approaches and attitudes to academics can be seen graphically in figure 55 below.

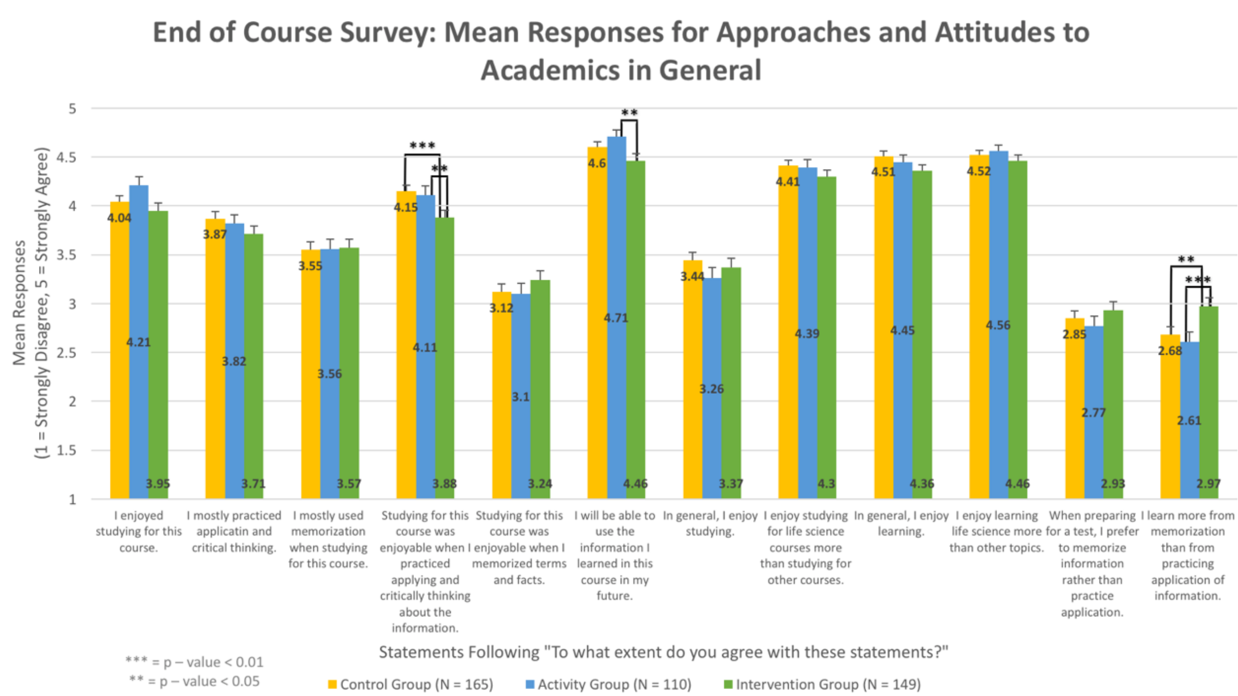

Figure 55: Mean responses for approaches and attitudes to academics in general by group with error bars for the standard error of the mean

Mean responses for only three of the nineteen items designed to evaluate personal significance of various aspects of future careers differed significantly amongst groups. The mean response for item "Working with living organisms rather than objects" was significantly higher in the control group than in the intervention group ($p = 0.0145$). The mode responses for this item, however, was similar amongst groups (control and intervention groups = 4 and activity control group = 5). While the mean responses for the item "Working with animals" did not significantly differ, the mode responses seemed to indicate a difference of opinion for this item (control = 1, activity control = 5 and intervention = 4). Mean responses for the intervention group indicate that they value working with something that is easy and simple significantly more than the control group ($p = 0.0055$). This was also indicated by the mode responses (control and activity control = 1 and intervention = 3). This trend was, however, flipped regarding mean responses for the item "Working with something that fits my values". In this instance, the control group's mean response was significantly higher than the intervention group's ($p = 0.0051$). The mode responses for this item, however, indicated that all groups "strongly agreed" with the statement. The mean responses for items evaluating items of personal significance can be seen graphically in figure 56 below.

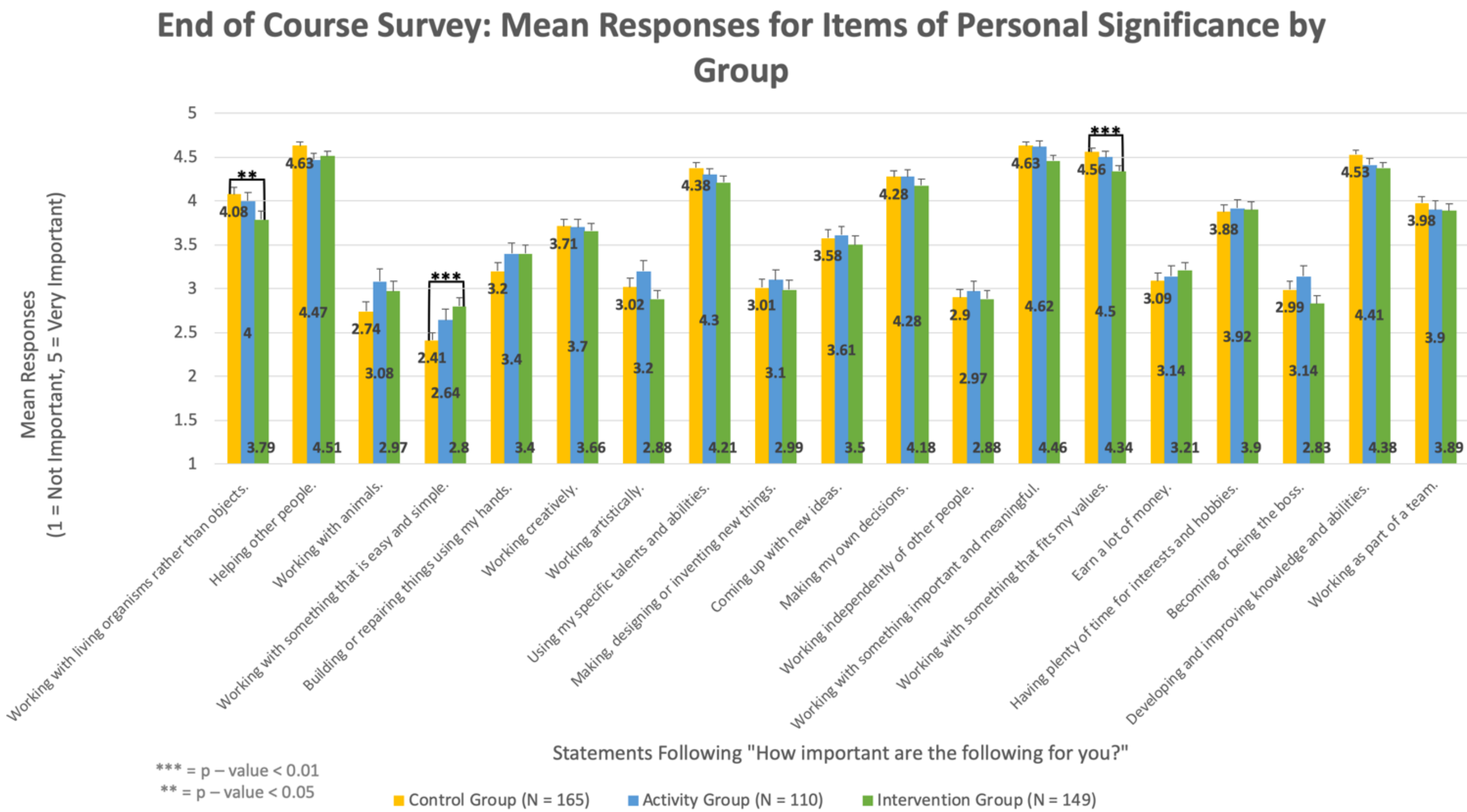

Figure 56: Mean responses for items of personal significance by group for the end of course survey with error bars for the standard error of the mean

The mean responses for both items designed to evaluate life science courses' impact and items designed to evaluate interest in nature and/or sciences outside of the classroom were similar amongst groups. Mean responses as well as mode responses indicate that all groups either "agreed" or "strongly agreed" that their life science courses would be helpful in everyday life, improve their career opportunities and increased their curiosity about the things that we cannot yet explain. Although there was no significant difference amongst mean responses for groups regarding how often they read or watched media about nature and/or science, the mode responses for the second item ("Watched TV shows, documentaries, or movies about nature and/or science") indicate that the activity control participated in these activities more often (control and intervention groups = 2 and activity control group = 4). The mean responses for all of these items can be seen graphically in figures 57 and 58 below.

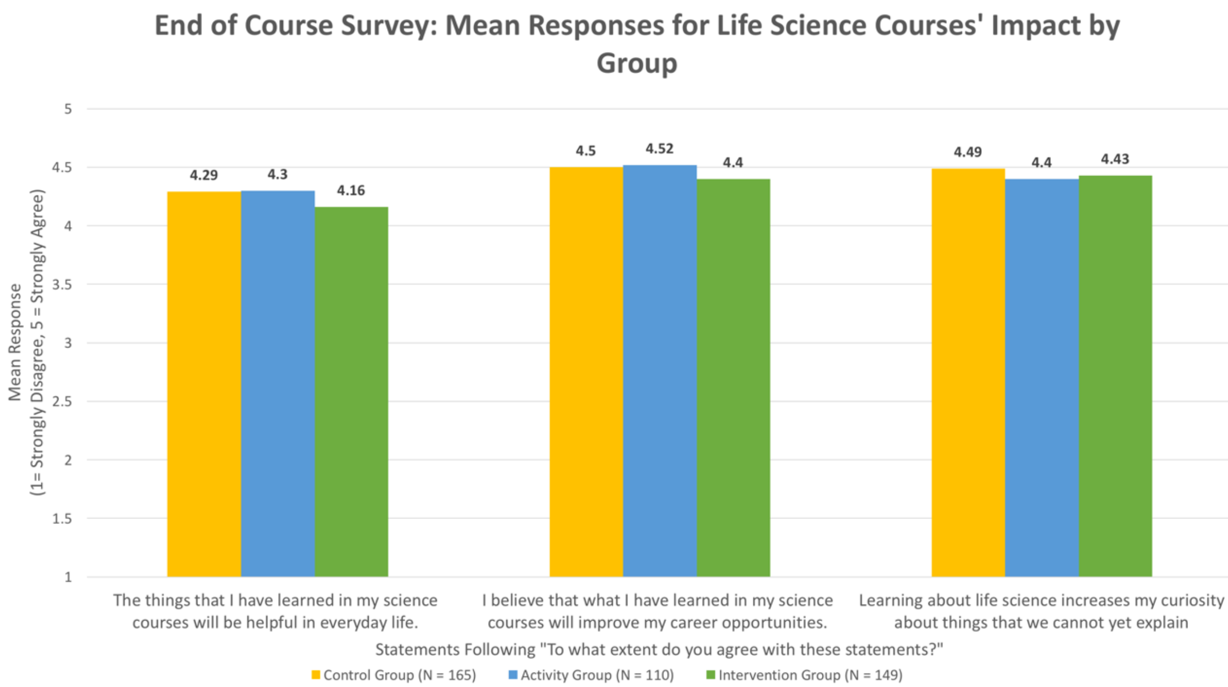

Figure 57: Mean responses for life science courses' impact by group for end of course survey

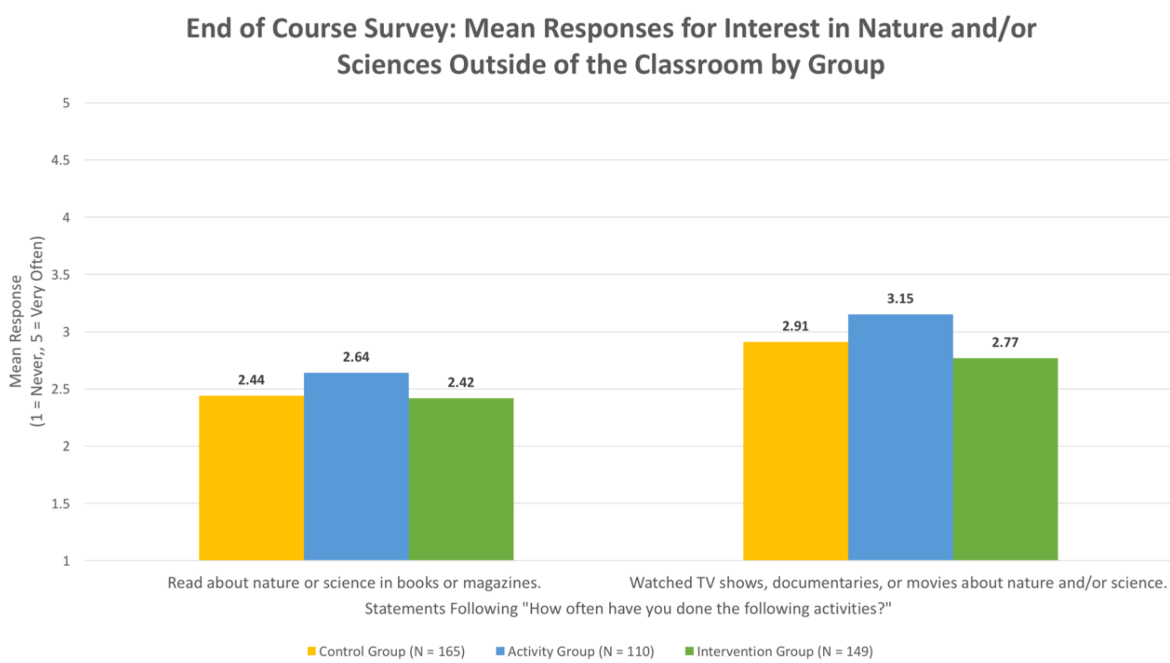

Figure 58: Mean responses for interest in nature and/or sciences outside of the classroom by group for end of course survey

5.1.4 Attitudes and Motivations for Education – Post Intervention Survey

5.1.4.1 Mean Responses

Feedback from students on their interactions with the model and the perceived impact that it had on their learning were overwhelmingly positive. Mode responses indicated that students either "agreed" or "strongly agreed" with all survey items. Mean responses for items designed to evaluate the perceived enjoyment of using the model to study specific concepts also indicated that students "agreed" that they enjoyed using the model to study muscle actions, neuron function, skeletal muscle organization, and sarcomeres (Figure 59).

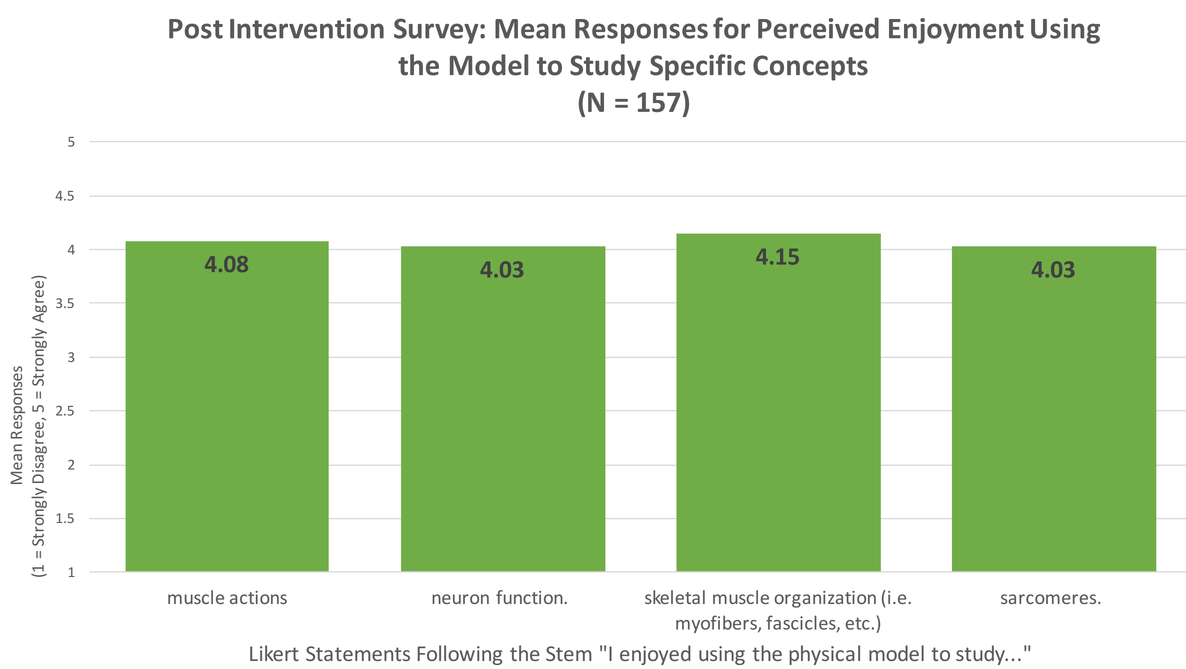

Figure 59: Mean responses for perceived enjoyment using the model to study specific concepts

Mean responses also indicated that students enjoyed completing the activity with the physical model and working with their groups while interacting with the model. However, the mean response for enjoyment of completing the activity was slightly lower than other response averages on this survey (Figure 60).

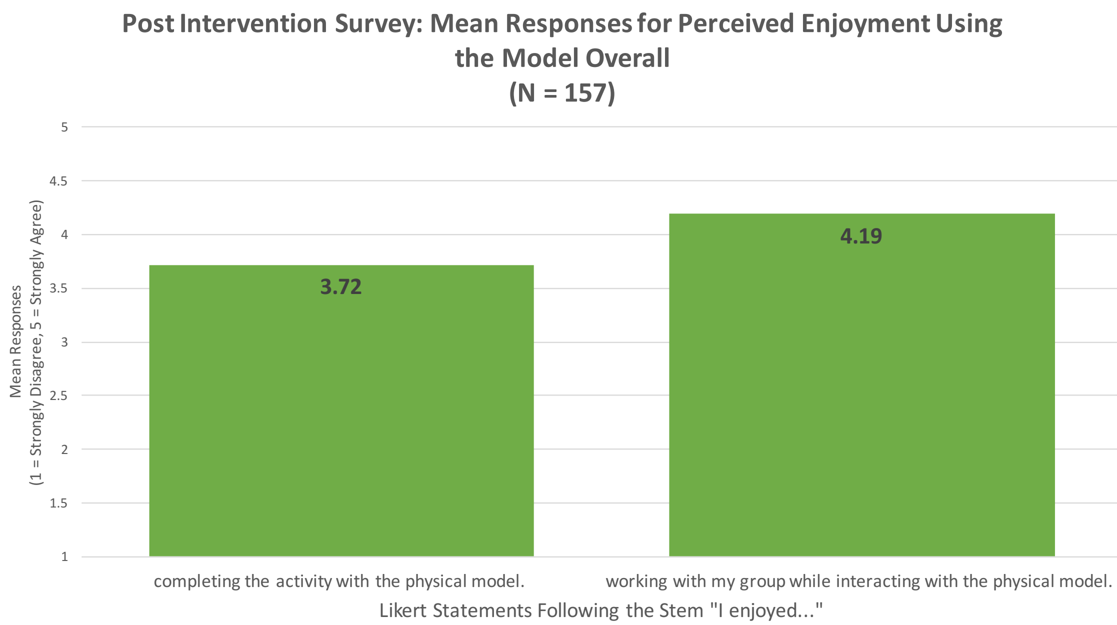

Figure 60: Mean responses for perceived enjoyment using the model overall

When asked whether the model helped them to understand specific concepts, the average mean response agreed with the statements (Figure 61). Concepts where students indicated that they believed the model helped the most were as follows (in order of increasing mean response): the underling mechanism of contraction and relaxation, the organization of a sarcomere, how thick and thin filaments interact during contraction, flexion and extension of joints, the organization of muscle cells within a muscle, and how a neuron gets from the central nervous system to an individual muscle cell.

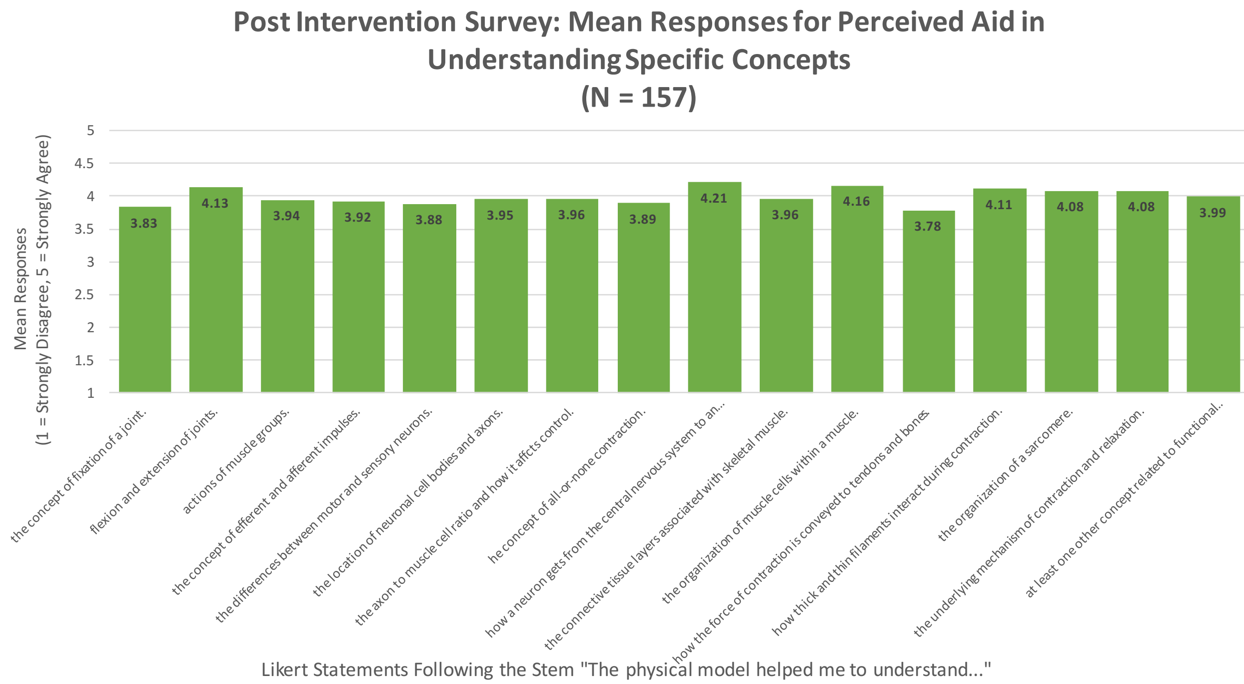

Figure 61: Mean responses for perceived aid in understanding specific concepts

When specifically asked about the ability of the model to aid with visualization of specific concepts, students again agreed with the statements. However, responses did indicate that the model was perceived to be more helpful with the visualization of contraction and relaxation of a muscle and mentally using the locations of muscles to deduce the action than it was for specific origins and insertions and muscle actions (Figure 62).

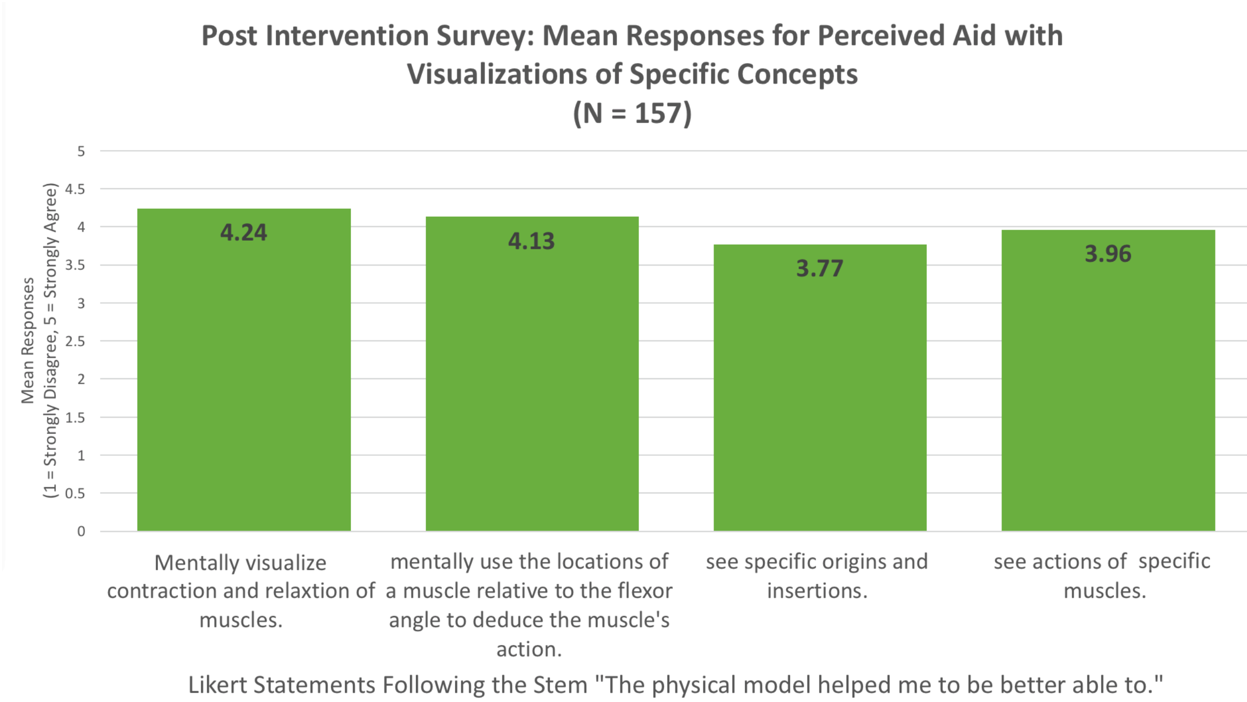

Figure 62: Mean responses for perceived aid with visualizations of specific concepts

The lowest mean responses on this survey were for items designed to evaluate the perceived impact of using the model as a study tool. Although all mode responses were a 4, or "agree", for these items, mean responses indicate that students may have been unsure about whether the model helped them to learn the material in a shorter amount of time or with less effort compared to their typical study methods. Mean responses did, however, seem to more strongly indicate that students believed the model helped them to learn the material more thoroughly and in depth than their typical study methods (Figure 63).

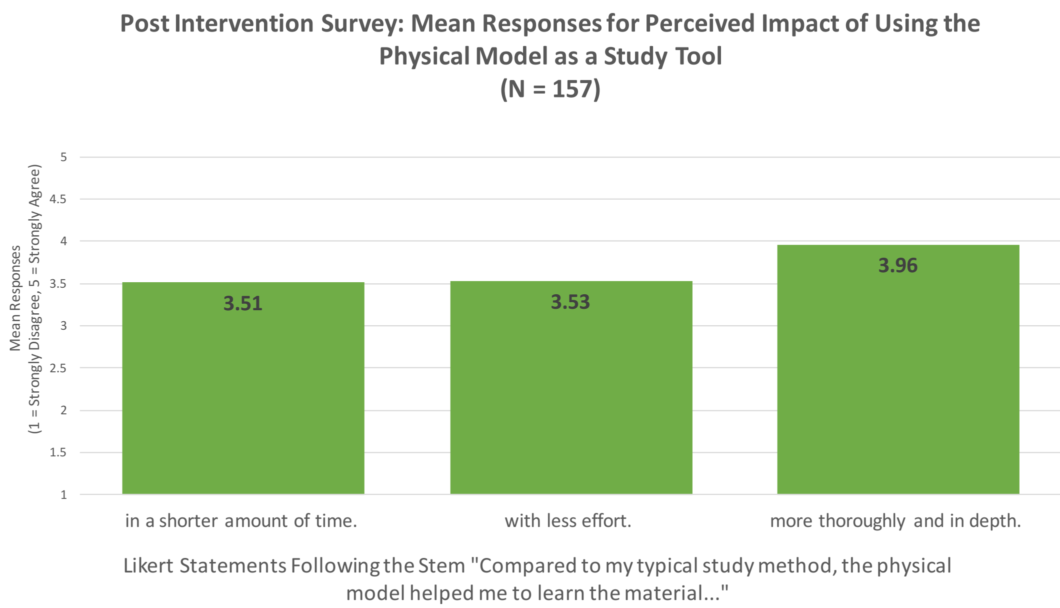

Figure 63: Mean responses for perceived impact of using the physical model as a study tool

Mean responses for items designed to evaluate the perceived use of the physical model as a study tool overall were also positive. Students were generally in agreement that they would use this method, or a similar method, to study other concepts in the Biomedical Anatomy course and other life science courses. However, mean responses did indicate that they were more likely to use this method to study for other concepts in the Biomedical Anatomy course than they were for other life science courses (Figure 64).

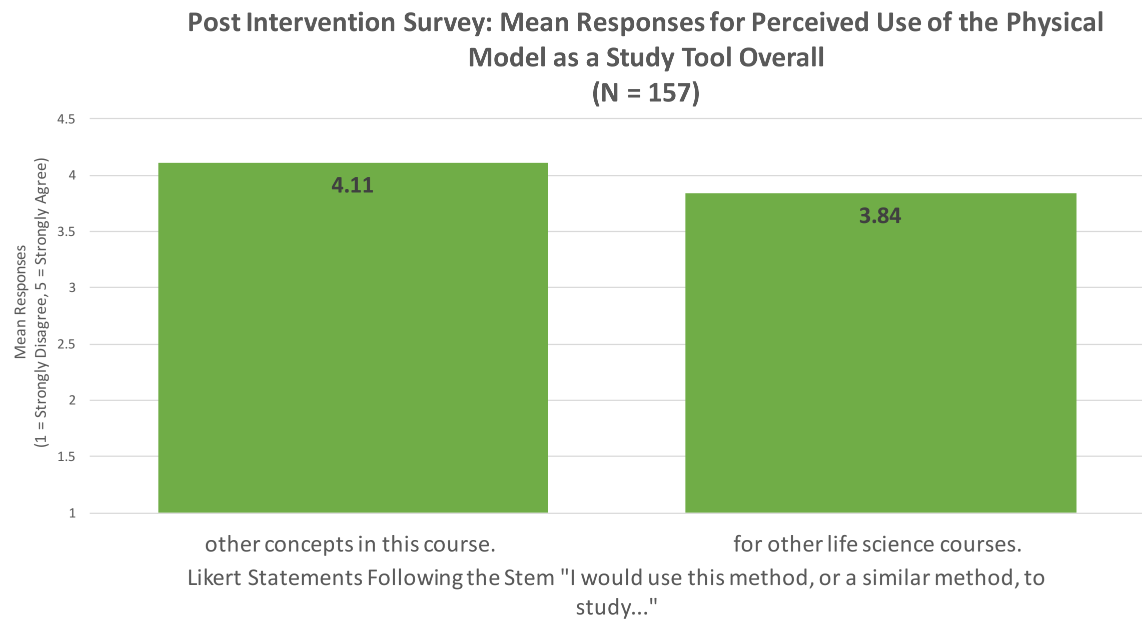

Figure 64: Mean responses for perceived use of the physical model as a study tool overall

Survey results indicate that students perceived the most positive impact from specific components of the model regarding its interaction and experimentation capabilities. The mode response for all four of these items was a 5, or “strongly agree”. Mean responses indicate that the students perceived the most benefit from being able to touch and manipulate the model, followed by seeing abstract concepts demonstrated, simulating muscle movement by pulling strings, and working in a group (Figure 65).

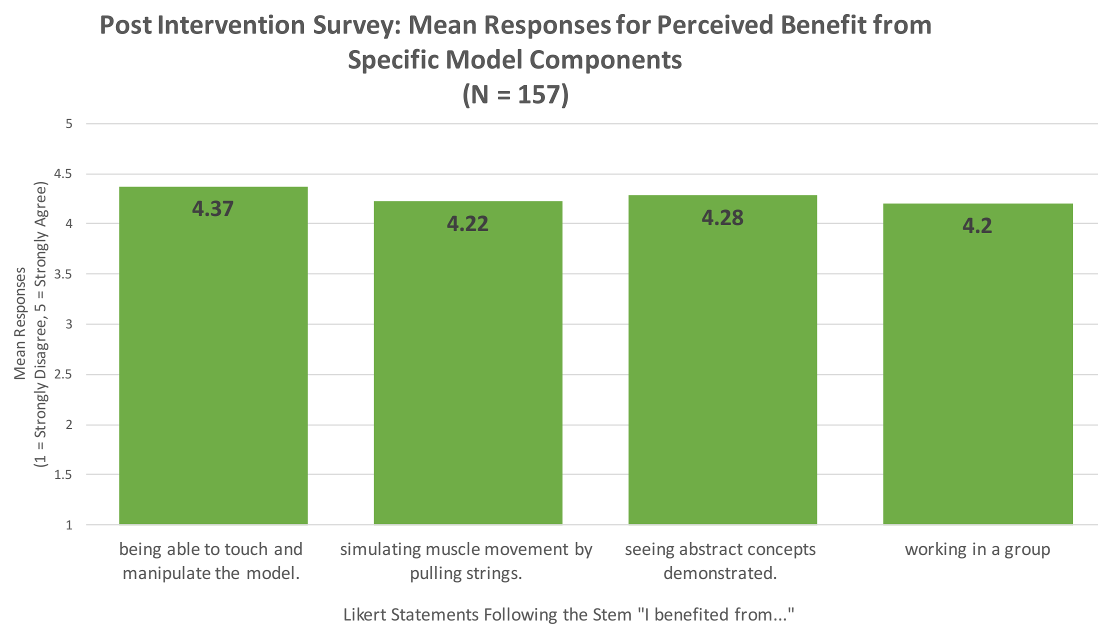

Figure 65: Mean responses for perceived benefit from specific model components

Finally, responses to items designed to evaluate the overall experience with the model indicated that the students perceived the experience as influential, easy and intuitive and beneficial. Although still in general agreement, student responses were lower for items evaluating whether their experience interacting with the model influenced their study plan for the rest of the course and whether interacting with the model was easy and intuitive. However, both mean and mode responses were higher for the item evaluating whether the students perceived any benefit from working with the model (mode = 5) (Figure 66).

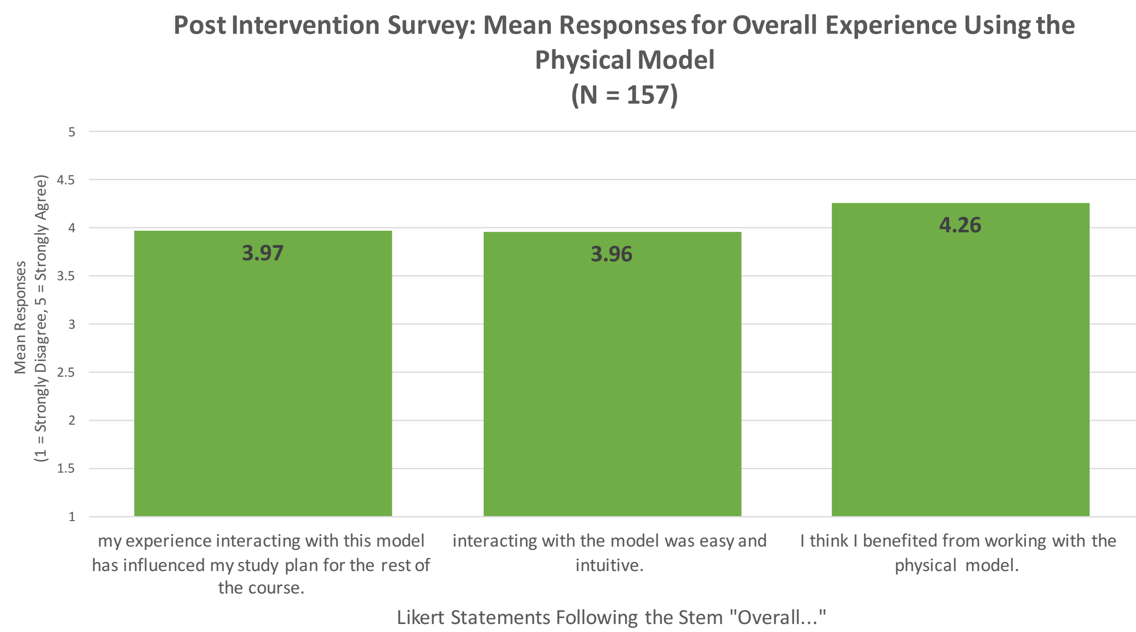

Figure 66: Mean responses for overall experience using the physical model

5.1.4.2 Correlations to Quiz Scores

Several of the survey items for this assessment had correlations with performance assessments. Specifically, for items related to thoracic limb myology and basic biomechanics, the survey item "The physical model helped me to better able to see specific origins and insertions" was negatively correlated with preliminary quiz scores. This indicated that students with higher scores on the Thoracic Limb Myology and Basic Biomechanics preliminary quiz were less likely to perceive a benefit from the model in regard to their ability to see specific origins and insertions (Rsquare = 0.0285, p = 0.0376). There were no correlations amongst the post intervention quiz scores or change in quiz scores for thoracic limb myology and basic biomechanics compared to the post intervention survey mean results.

Similarly, students who scored higher on the Skeletal Muscle Histology and Physiology preliminary quiz were less likely to perceive benefit from the model regarding their ability to understand how a neuron gets from the central nervous system to an individual muscle cell (Rsquare = 0.0278, p = 0.0401). In addition, students who scored higher on the post intervention quiz or had a higher change in quiz score (from preliminary quiz to post intervention quiz) for this same topic were less likely to perceive benefit from the model regarding any additional musculoskeletal anatomy concepts (post quiz Rsquare = 0.0353, p = 0.0322, and change in score Rsquare = 0.0417, p = 0.0197) and were more likely to disagree that interacting with the model was easy and intuitive (post quiz Rsquare = 0.0394, p = 0.023, and change in score Rsquare = 0.0399, p = 0.0221).

Peripheral nervous system performance assessments were more positively correlated with the perceived impact of the model. Students with lower scores on the Peripheral Nervous System preliminary quiz were more likely to perceive that the model helped them to understand the location of the components of neurons (Rsquare = 0.0308, p = 0.0329), to learn the material in a shorter amount of time (Rsquare =0.0353, p = 0.0227) and with less effort (Rsquare = 0.0635, p = 0.0021), and more likely to agree that they would use this method, or something similar, to study other concepts in the Biomedical Anatomy course (Rsquare = 0.0427, p = 0.0124). In contrast, students who had a greater change in quiz score were less likely to agree that the model helped them to learn the material with less effort than their typical study methods (Rsquare = 0.0303, p = 0.0350). There were no correlations amongst the post intervention quiz scores for the peripheral nervous system and the post intervention survey mean results.

Performance assessments for integration of material had the most correlations to items from the post intervention survey and the majority of these correlations were positive. Students with higher post intervention quiz scores and students with higher changes in quiz scores were more likely to agree that the model helped them to understand differences between motor and sensory neurons (post quiz Rsquare = 0.0265, p = 0.0479, and change in score Rsquare = 0.02622, p = 0.0493), the locations of neuronal components (post quiz Rsquare = 0.0282, p = 0.0412, and change in score Rsquare = 0.0358, p = 0.0214), the axon to muscle cell ratio and its effect on control (post quiz Rsquare = 0.0269, p = 0.0464, and change in score Rsquare = 0.0498, p = 0.0064), and the concept of all-or-none contraction (post quiz Rsquare = 0.0308, p = 0.0336, and change in score Rsquare = 0.0389, p = 0.0166). The same students were also more likely to agree that the model helped them to learn the material in a shorter amount of time (post quiz Rsquare = 0.0285, p = 0.0402, and change in score Rsquare = 0.0287, p = 0.0396). In addition, students with a higher post intervention quiz score were more likely to agree that the model helped them to understand efferent and afferent impulses (Rsquare = 0.0338, p = 0.0258) and students with a higher change in quiz scores were more likely to agree that the model helped them to understand how the force of contraction is conveyed to tendons and bones (Rsquare = 0.0269. p = 0.0466). There was, however, a negative correlation between post intervention quiz scores and the perceived enjoyment of working in a group while interacting with the model indicating that students with higher post quiz scores were less likely to perceive that working in a group while interacting as enjoyable (Rsquare = 0.0315, p = 0.0316). There were no correlations amongst the preliminary integration quiz scores and the post intervention survey mean results.

A summary of the correlations amongst performance assessments and perceived impact of the intervention model can be seen in table 11 below.

Correlations Amongst Performance Assessments & Perceived Impact of Intervention Model by Performance Assessment Topic *(only performance assessment items that had correlations with perceived impact of intervention model are listed)*		
Performance Assessment	**Positively Correlated Survey Items**	**Negatively Correlated Survey Items**
Thoracic Limb Myology and Basic Biomechanics		
Preliminary Quiz	*none*	*”The physical model helped me to be better able to see specific origins and insertions.”*
Skeletal Muscle Histology and Physiology		
Preliminary Quiz	*none*	*”The physical model helped me to understand how a neuron gets from the central nervous system to an individual muscle cell.”*
Post Intervention Quiz	*none*	*”The physical model helped me to understand at least one other concept related to functional musculoskeletal anatomy not mentioned here.”*
		“Overall, interacting with the model was easy and intuitive.”
Change in Quiz Score	*none*	*”The physical model helped me to understand at least one other concept related to functional musculoskeletal anatomy not mentioned here.”*
		“Overall, interacting with the model was easy and intuitive.”
The Peripheral Nervous System		
Preliminary Quiz	*”The physical model helped me to understand the location of neuronal cell bodies and axons.”*	*none*
	“Compared to my typical study method, the physical model helped me to learn the material in a shorter amount of time.”	
	“Compared to my typical study method, the physical model helped me to learn the material with less effort.”	
	“I would use this method, or a similar method, to study other concepts in this course.”	
Change in Quiz Score	*none*	*“Compared to my typical study method, the physical model helped me to learn the material with less effort.”*
Integration		
Post Intervention Quiz	*“Compared to my typical study method, the physical model helped me to learn the material in a shorter amount of time.”*	*“I enjoyed working with my group while interacting with the physical model.”*
	”The physical model helped me to understand the axon to muscle cell ratio and how it affects control.”	
	“The physical model helped me to understand the differences between motor and sensory neurons.”	
	”The physical model helped me to understand the location of neuronal cell bodies and axons.”	
	”The physical model helped me to understand the concept of all-or-none contraction.”	
	”The physical model helped me to understand the concept of efferent and afferent impulses.”	
Change in Quiz Score	*“Compared to my typical study method, the physical model helped me to learn the material in a shorter amount of time.”*	*none*
	”The physical model helped me to understand the axon to muscle cell ratio and how it affects control.”	
	“The physical model helped me to understand the differences between motor and sensory neurons.”	
	”The physical model helped me to understand the location of neuronal cell bodies and axons.”	
	”The physical model helped me to understand the concept of all-or-none contraction.”	
	“The physical model helped me to understand how the force of contraction is conveyed to tendons and bones.”	

Table 11: Correlations amongst performance assessments and perceived impact of intervention model by performance assessment topic

5.1.5 Attitudes and Motivations for Education – Future Course Survey

Only two of the twelve items designed to evaluate students approaches and attitudes to academics in general had mean results with significant differences amongst groups. These results indicate that students in the intervention group were significantly more likely to have used memorization as a study strategy than both the control ($p = 0.0303$) and activity control ($p = 0.0038$) groups. The mode responses for this item, however, indicate that students in the intervention and control groups were equally likely to have used memorization, while students in the control group were less likely to have used memorization (control and intervention = 4, activity control = 2). Mode responses for the item “Studying for this course was enjoyable when I memorized terms and facts” were also varied amongst groups and indicated that students in the intervention group enjoyed using memorization (control and activity control = 2, intervention = 4). Mean responses for these items also indicate that students in the activity control group enjoyed studying for life science courses more than other courses significantly more than students in the control group ($p = 0.0201$). Mode responses for this same item, however, indicate that all three groups “strongly agreed” that they enjoyed studying for life sciences courses more than other courses. The mean responses for these items can be seen graphically in figure 67 below.

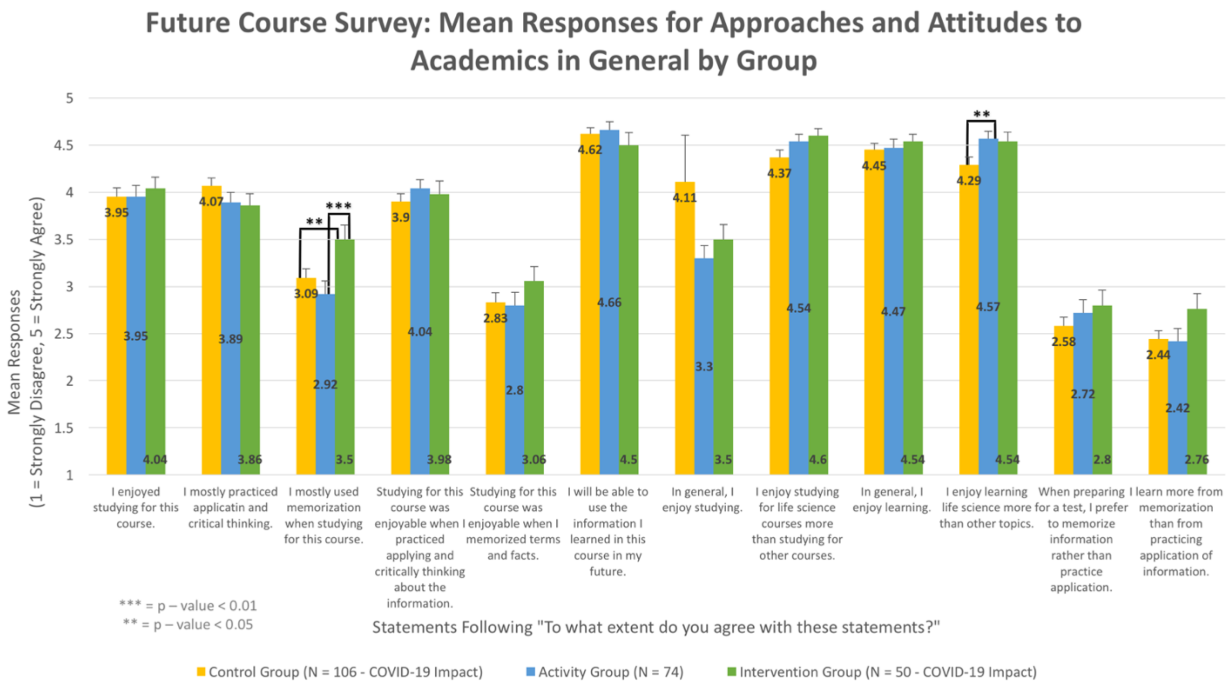

Figure 67: Mean responses for approaches and attitudes to academics in general by group for future course survey with error bars for the standard error of the mean

Three of the ten mean responses to items designed to evaluate personal significance of various aspects of future careers differed significantly amongst groups. Mean responses for the item "Using my specific talents and abilities" indicate that the activity control group perceived this aspect as significantly more important than the control group ($p < 0.0001$). Mode responses only indicated a slight difference amongst groups for this item (control and intervention = 4, activity control = 5). Mode responses did indicate a difference amongst groups regarding the importance of making, designing, or inventing new things (control = 4, activity control = 3 and intervention = 2). Mean responses also indicate a that students in the control group value working with something important and meaningful significantly less than both the activity control (p = 0.0016) and the intervention (p = 0.0264) groups. Mode responses for this item, however, were consistent amongst groups (all groups = 5). Both the mean and mode responses indicate that students in the control group placed more value on becoming or being the boss. Mean responses indicate a significant difference between responses from the control group and responses from the intervention group for this item (p = 0.0047), while mode responses only indicate the same response for the activity and control group, with a lower response from the intervention group (control and activity control = 4, intervention = 2). The mean responses for these items can be seen graphically in figure 68 below.

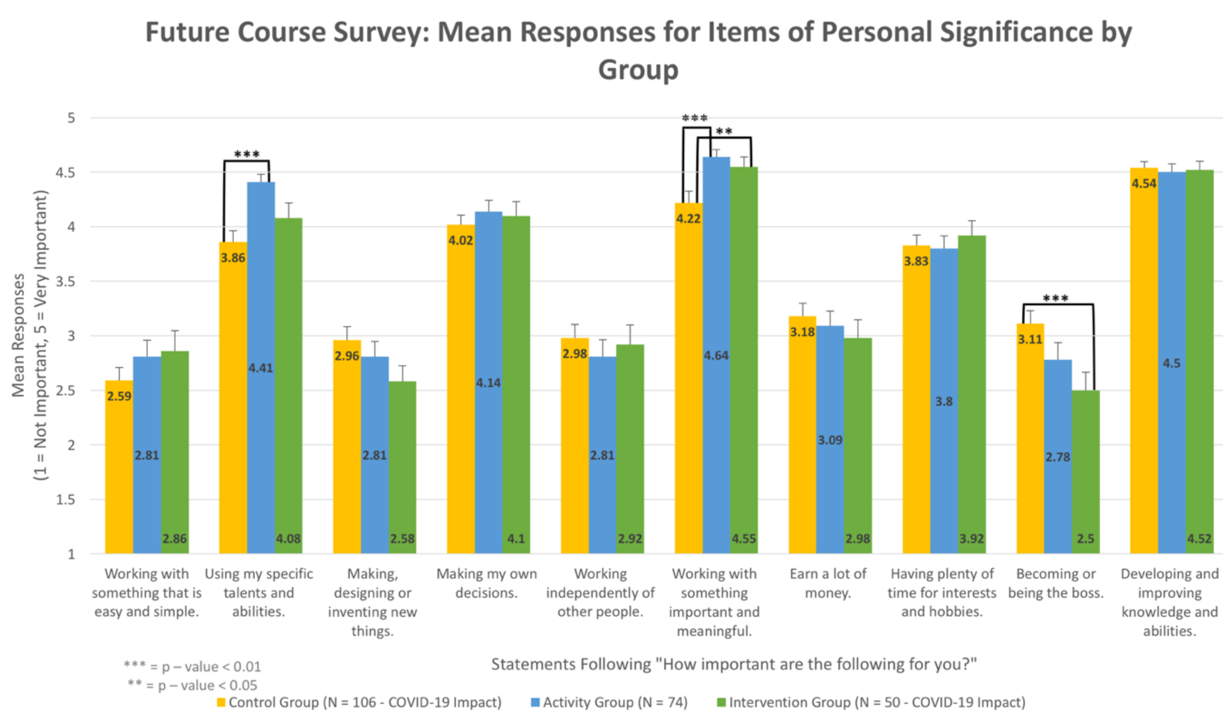

Figure 68: Mean responses for items of personal significance by group for end of course survey with error bars for the standard error of the mean

Both the mean and mode responses for items designed to evaluate life science courses' impact and items designed to evaluate interest in nature and/or sciences outside of the classroom were similar amongst groups. Mean responses as well as mode responses indicate that students in all groups either "agreed" or "strongly agreed" that their life science courses would be helpful in everyday life, improve their career opportunities and increased their curiosity about the things that we cannot yet explain (all modes = 5). Mean and mode responses also indicate that students in all groups did not watch or read media about nature and/or science often (all modes = 2). The mean responses for these items can be seen graphically in figures 69 and 70 below.

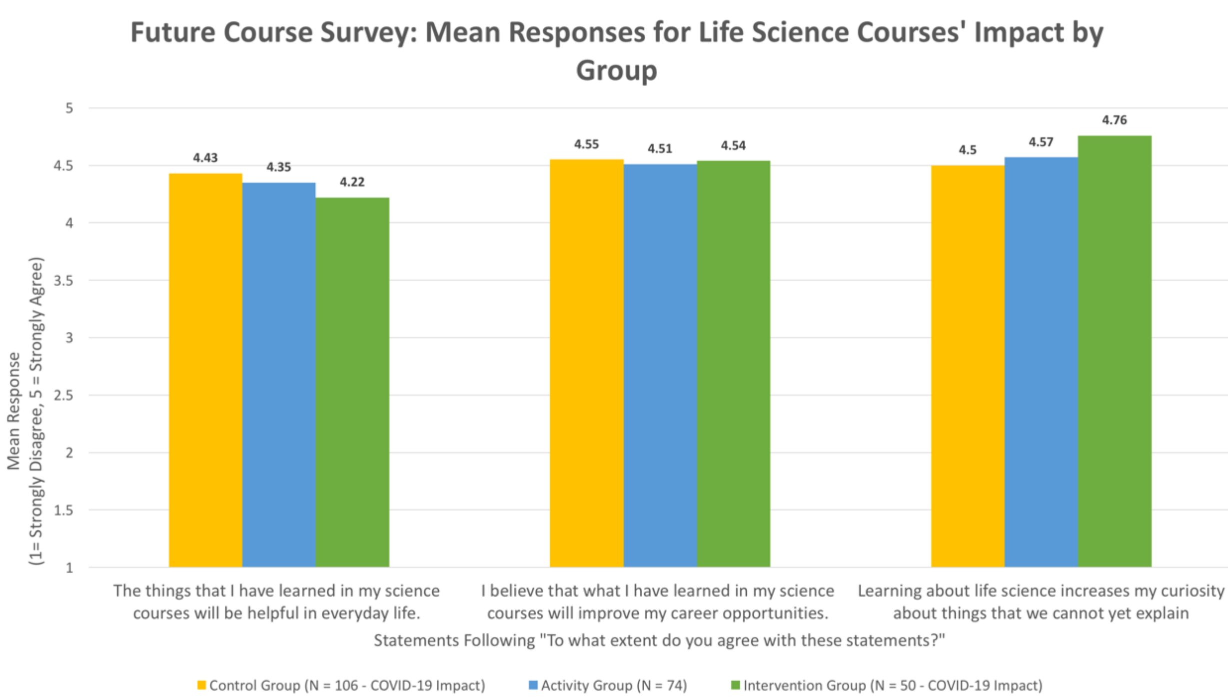

Figure 69: Mean responses for life science courses' impact by group for end of course survey

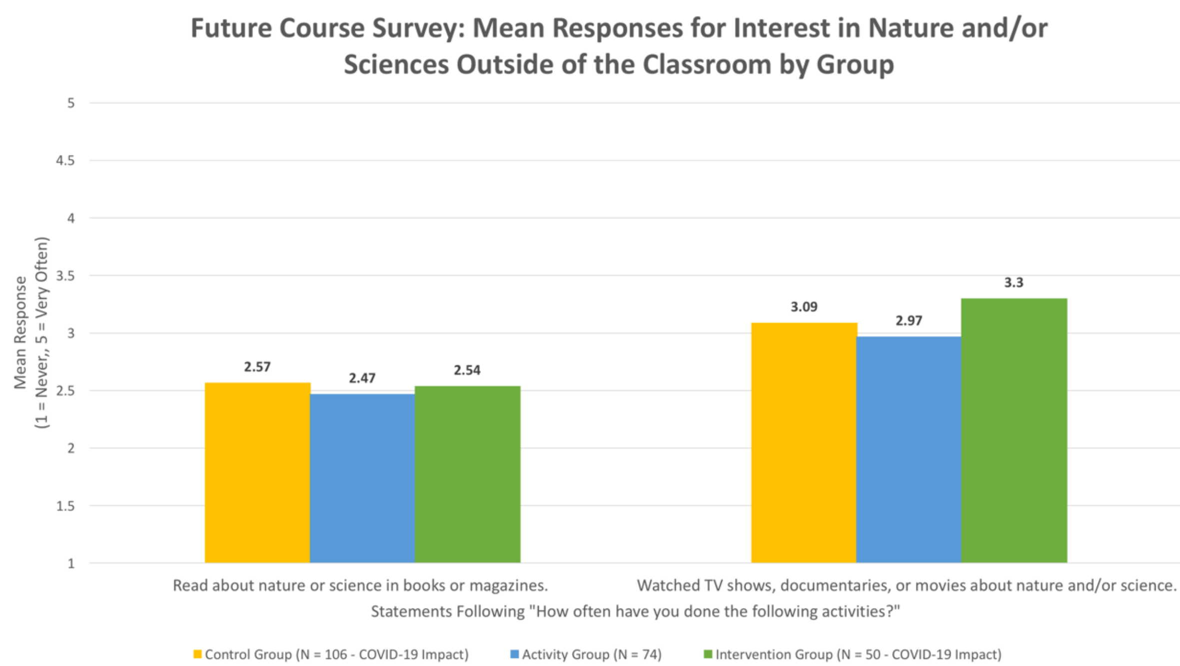

Figure 70: Mean responses for interest in nature and/or sciences outside of the classroom by group for end of course survey

5.1.6 Change Over Time

Throughout the study student responses to various survey assessment items changed. Items that were repeated throughout the study, and were therefore assessed for change over time, include students' goals, approaches and attitudes towards academics in general, items of personal significance, life science courses' impact, interest in nature and/or science outside of the classroom and approaches and attitudes for past courses.

5.1.6.1 Most Important Goals

Results indicate that students' most important goal changed throughout the duration of the two-semester study.

For the control group, a majority of students choose "Get an 'A'" as their top priority on the first day of the anatomy course (44%), following the first exam (42%) and following the second exam (41%). However, after the third exam students seemed shifted their priorities so that “Get an ‘A’” (33%) was second to “Learn the material” (44%). Just before the final exam students were split with 38% choosing “Get an ‘A’” as their top priority, and 38% choosing “Learn the material”. However, students again seemed to shift their priorities after the second semester of the study as more than half (51%) reported that their top priority was to “Learn the material”, while only 23% reported that their top priority was to “Get an ‘A’”. This change in time can be seen in figure 71 below.

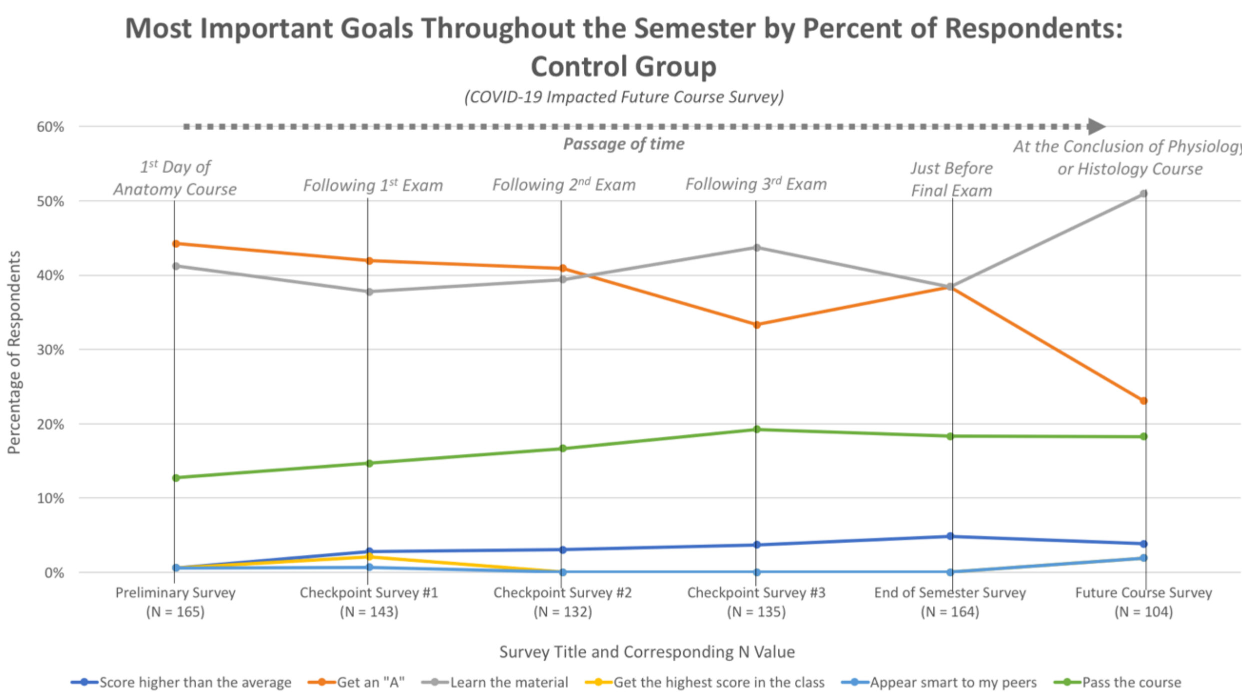

Figure 71: Most important goals throughout the semester by percent of respondents, control group

The activity control groups’ top priorities seemed to shift a bit more than the control groups’ top priorities throughout the two semesters. Students in this group started off with a majority reporting that “Learn the material” was their top priority (33%) with “Get an ‘A’” taking a close second (30%). However, after the first exam priorities for these students shifted so that “Get an ‘A’” was now most important (39%), and “Learn the material” was only second in comparison (32%). Following the second exam, “Get an ‘A’” was still most important for students (36%), but it was very closely followed by “Learn the material” (35%). “Learn the material” (45%) again seemed to take precedence over “Get an ‘A’” (34%) after the third exam, but only for a short time as “Get an ‘A’” (40%) again became the top priority for students over “Learn the material” (32%) just before the final exam. However, similar to the results from the control group, students’ priorities were drastically different at the conclusion of the second semester. At this point, “Learn the material” had taken a large step up from second most important to most important for almost half of the students (47%). “Get an ‘A’” went from most important to third most important with only 23% of students. Surprisingly, “Pass the course” moved into the second most important position with 28% of students when it had only ever been third in priority throughout the first semester of the study. This change in time can be seen in figure 72 below.

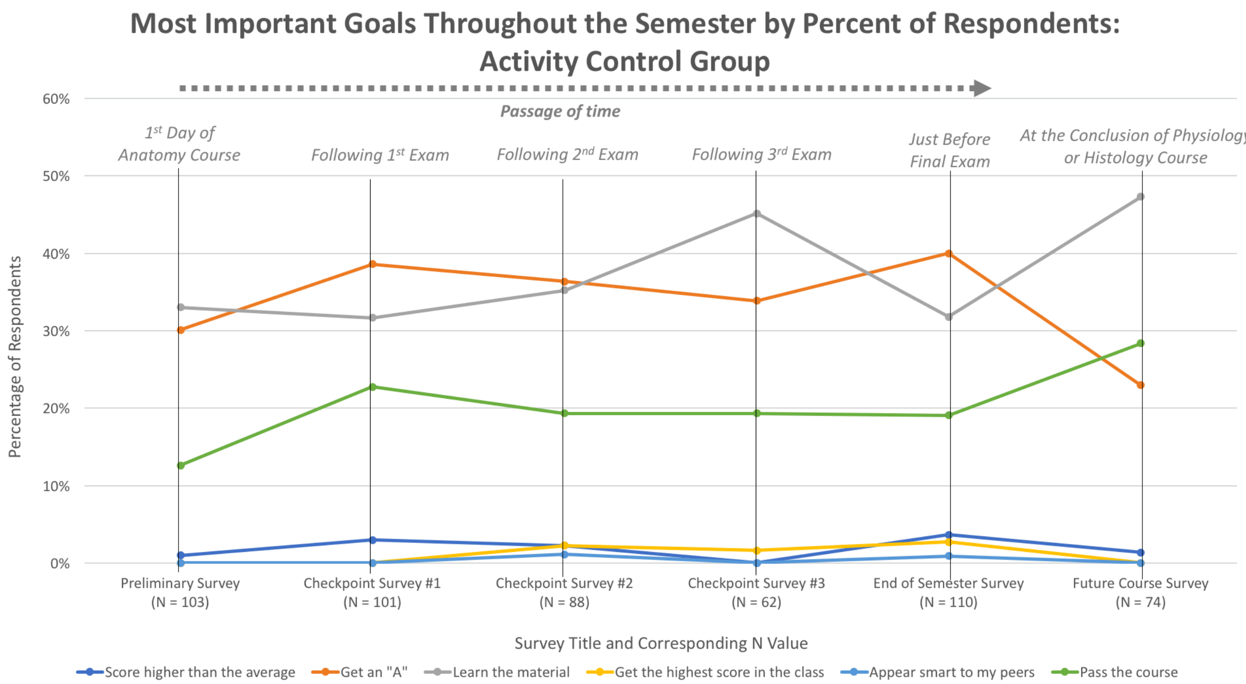

Figure 72: Most important goals throughout the semester by percent of respondents, activity control group

Although the top priorities for the intervention group did change, it was only slightly throughout both semesters. However, by the end of the second semester "Get an 'A'" had been replaced as top priority by "Learn the material". Similar to the control group, students in the intervention group began the Biomedical Anatomy course with "Get an 'A'" as their top priority (42%) and "Learn the material" (35%) as their second priority. Just before the first exam after interacting with the physical model, "Learn the material" moved up to match "Get an 'A'" with 38% of students choosing each as their top priority. Following the first exam, however, "Get an 'A'" was again the most important with 37% of students, but "Learn the material" was not far behind with 33% of students. "Get an 'A'" (33%) and "Learn the material" (32%) were nearly equal in importance again after the second exam and following the third exam they both had 34% of students reporting that they were the most important goal. Just before the final exam, however, "Learn the material" (35%) did finally surpass "Get an 'A'" (32%) as the top priority and it maintained that status through the second semester ("Learn the material" = 42%, "Get an 'A'" = 26%). This change in time can be seen in figure 73 below.

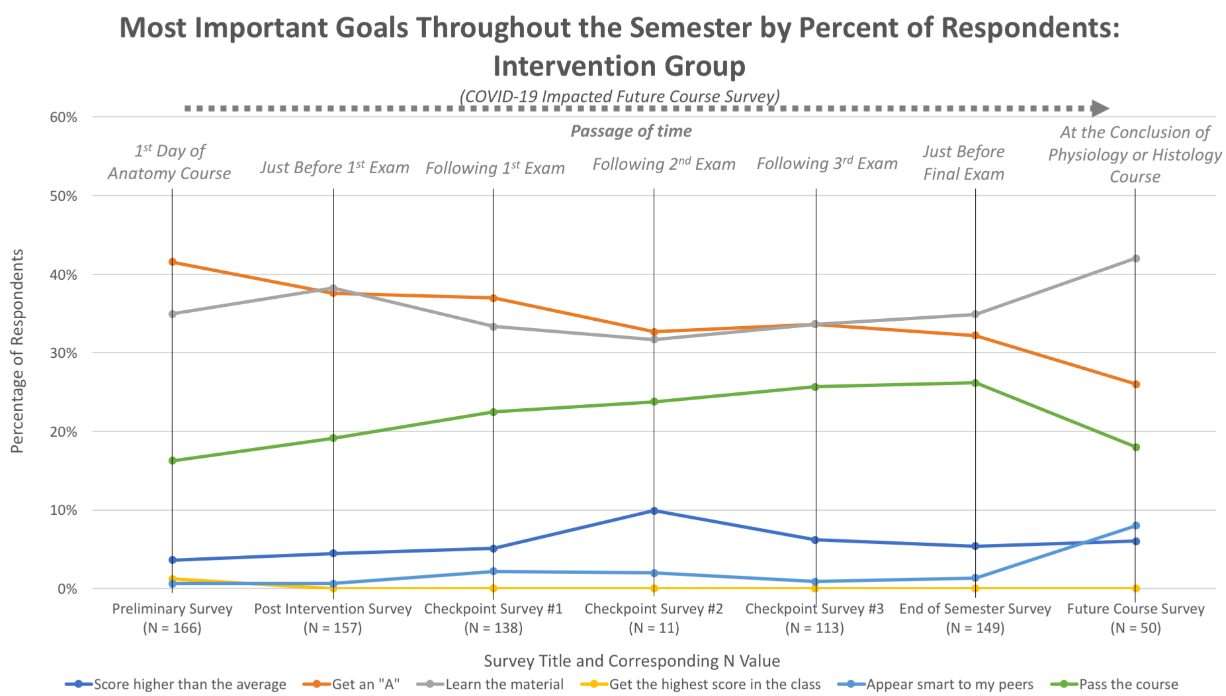

Figure 73: Most important goals throughout the semester by percent of respondents, intervention group

5.1.6.2 Approaches and Attitudes Towards Academics in General

Changes to the approaches and attitudes towards academics in general for the control group were significant for items regarding studying, the enjoyment of learning life sciences and learning from memorization over application of information. Students in this group seemed to find more enjoyment in studying throughout the study. There was a significant increase in mean responses for this item from the preliminary survey to the future courses survey (p = 0.0142) and from the end of course survey to the future course survey (p = 0.043). Similarly, there was a significant increase in mean responses for the item “I enjoy studying for life science courses more than studying for other courses” from the preliminary survey to the end of course survey (p = 0.0109). Mean responses also indicated that there was a significant increase in how much the students enjoyed learning life sciences courses over other topics from the preliminary survey to the end of course survey (p = 0.0093), but a significant decrease from the end of course survey to the future course survey (p = 0.0124). Mean responses for students in this group also indicate a significant increase in the perceived benefit of memorization over application of information from the preliminary survey to the end of course survey (p = 0.0011). This change over time can be seen in figure 74 below.

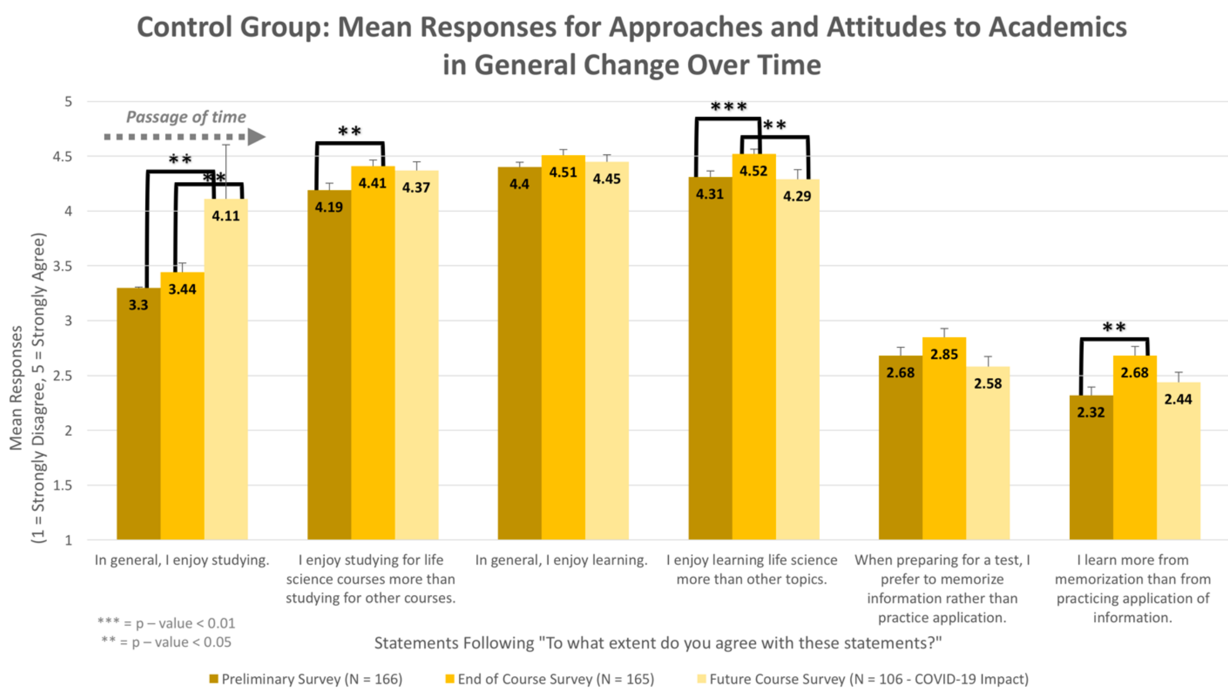

Figure 74: Change over time in mean responses for approaches and attitudes to academics in general, control group with error bars for the standard error of the mean

The activity control group also had significant changes in their mean responses regarding the enjoyment of both studying and learning life science over other topics. In addition, there was a significant change in their general enjoyment of learning. Mean responses from students in the activity control group indicate that their enjoyment of studying life sciences over other courses, their general enjoyment of learning, and their enjoyment of learning life sciences over other topics increased significantly from the preliminary survey to the end of course survey ($p < 0.0001$ for all items) and from the preliminary survey to the future course survey ($p < 0.0001$ for all items). This change over time can be seen in figure 75 below.

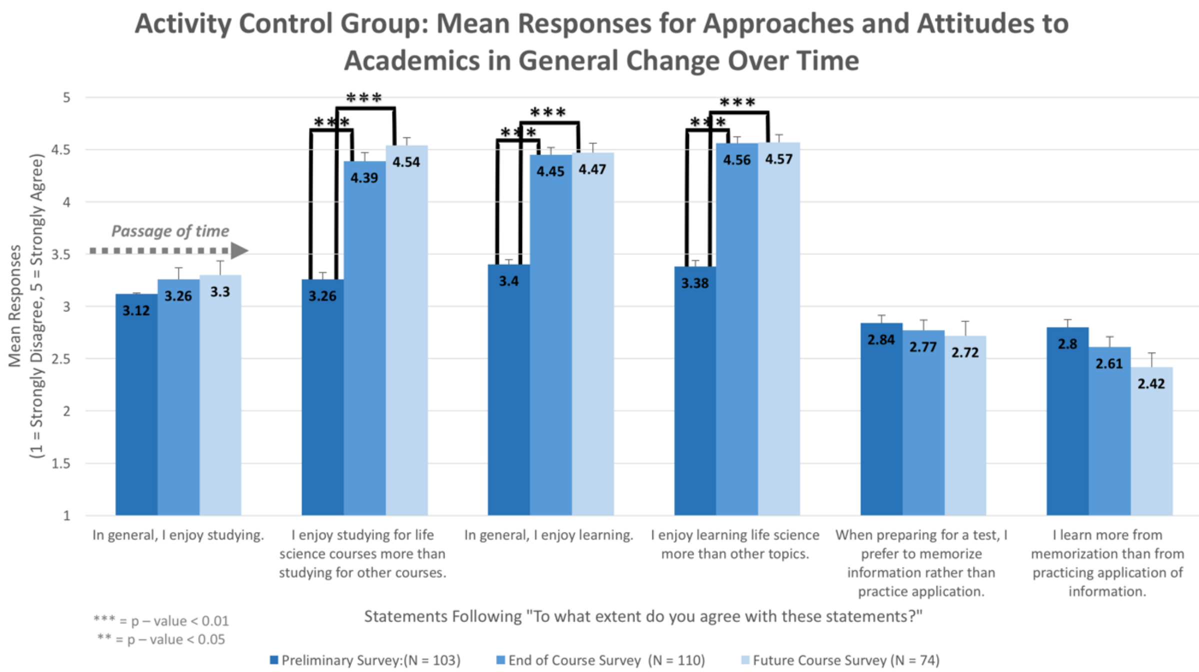

Figure 75: Change over time in mean responses for approaches and attitudes to academics in general, activity control group with error bars for the standard error of the mean

Like the control group and the activity control group, the intervention group had significant changes amongst their responses in regard to their enjoyment of studying life sciences over other courses. This group also had significant changes in their general enjoyment of learning, similar to the activity control group, and significant changes in learning from memorization over application of information, similar to the control group. Mean responses indicate a significant increase for the item "I enjoy studying for life sciences more than studying for other courses", amongst all of the surveys from the preliminary survey to the end of course survey (p = 0.0199), the end of course survey to the future course survey (p = 0.0199) and from the preliminary survey to the future course survey (p <0.0001). A significant increase in the general enjoyment of learning was also indicated by the mean responses from the preliminary survey to the future course survey (p = 0.0044). Finally, a significant increase from the preliminary survey to the end of course survey was also seen for the item “I learn more from memorization than from practicing application of information” (p <0.0001). This change over time can be seen in figure 76 below.

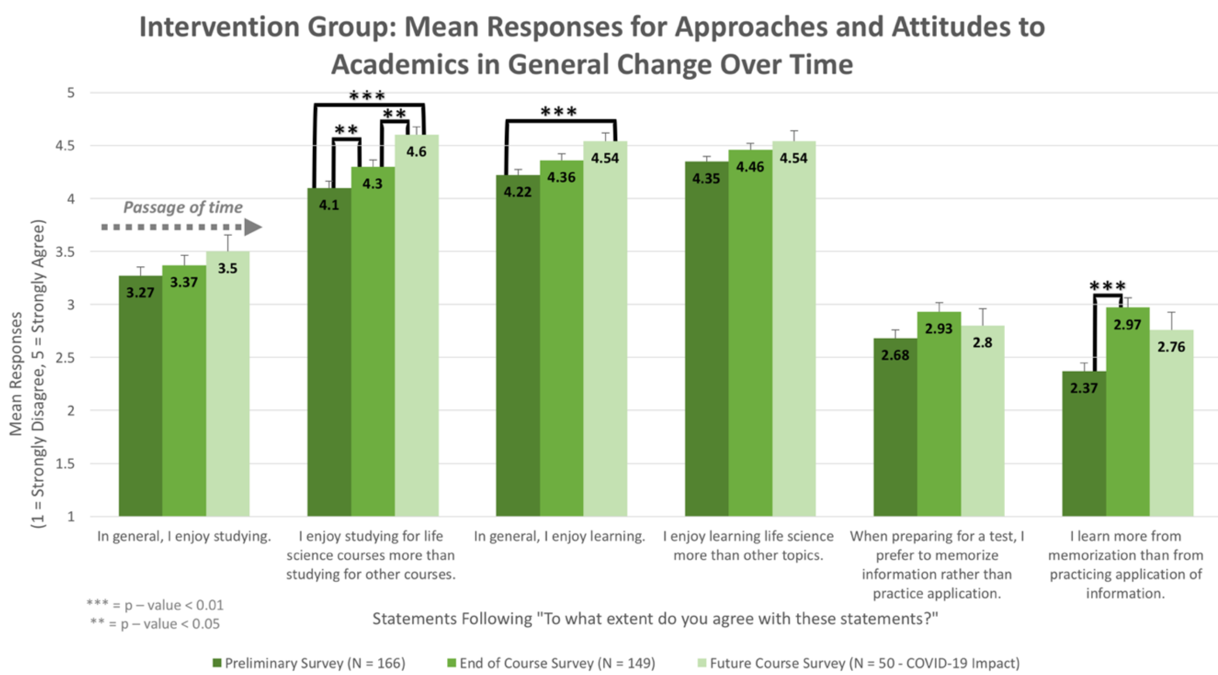

Figure 76: Change over time in mean responses for approaches and attitudes to academics in general, intervention group with error bars for the standard error of the mean

5.1.6.3 Items of Personal Significance

There were nineteen items evaluating personal significance of various aspects for future careers on both the preliminary survey and the end of course survey. However, there were only ten items for this evaluation on the future course survey.

Of the items included on both the preliminary survey and the end of course survey, three had significant differences in mean responses for the control group, two of those items were also included on the future course survey. Mean responses indicated a significant increase in the importance of working with living organisms rather than objects from the beginning of the Biomedical Anatomy semester to the end of the semester ($p = 0.0004$). These responses also indicated a decrease in the importance in using specific talents and abilities as well as working with something meaningful and important from the preliminary survey to the future course survey (specific talents and abilities $p < 0.0001$, something meaningful and important $p = 0.0003$) and from the end of course survey to the future course survey ($p < 0.0001$ for both items). This change over time can be seen in figure 77 below.

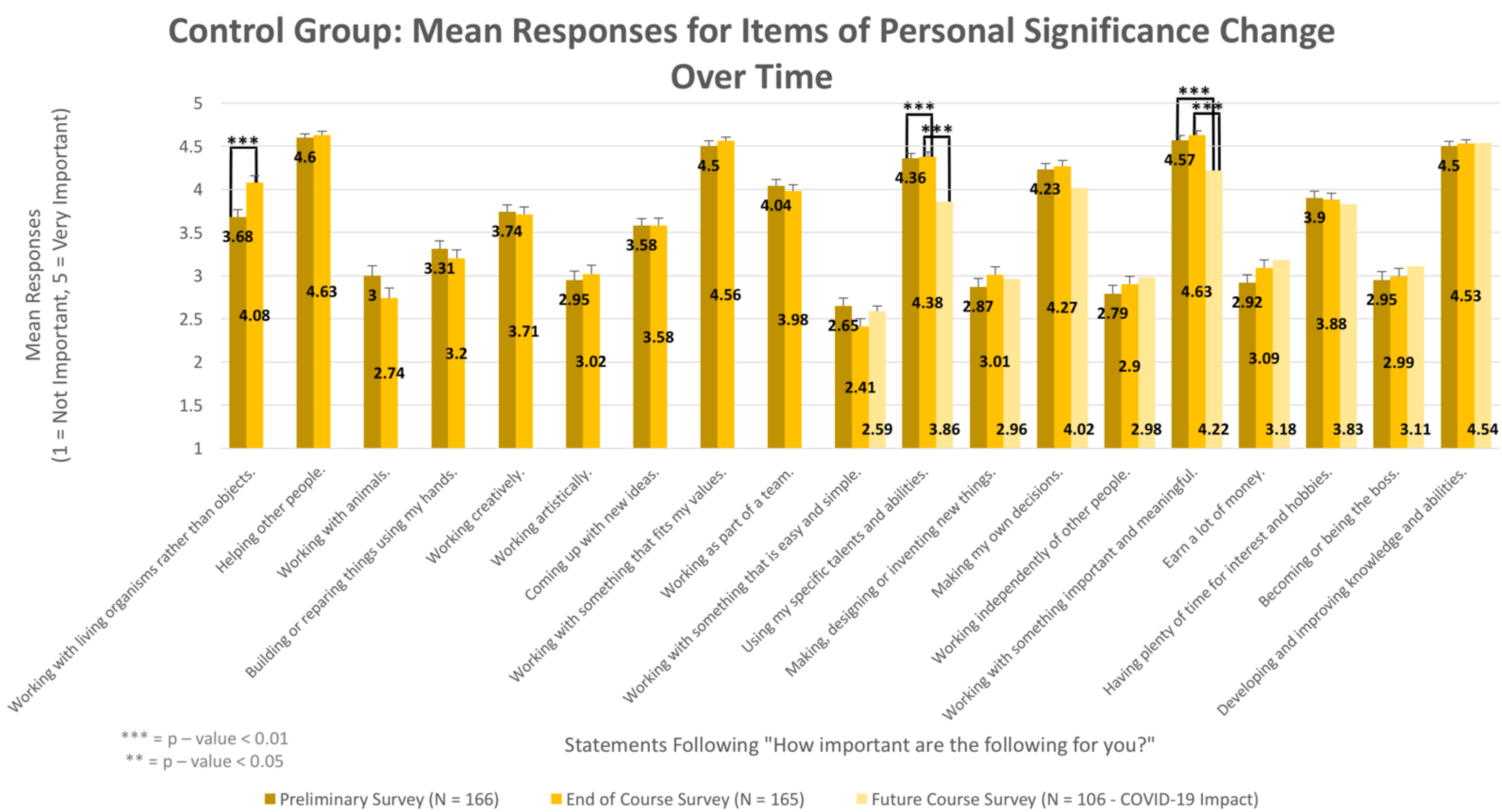

Figure 77: Change over time in mean responses for items of personal significance, control group with error bars for the standard error of the mean

Mean responses for items designed to evaluate personal significance of various aspects for future careers for the activity control group only indicated one significant difference. This difference was a significant increase in the importance of working as a team from the preliminary survey to the end of course survey ($p = 0.0376$). This change over time can be seen in figure 78 below.

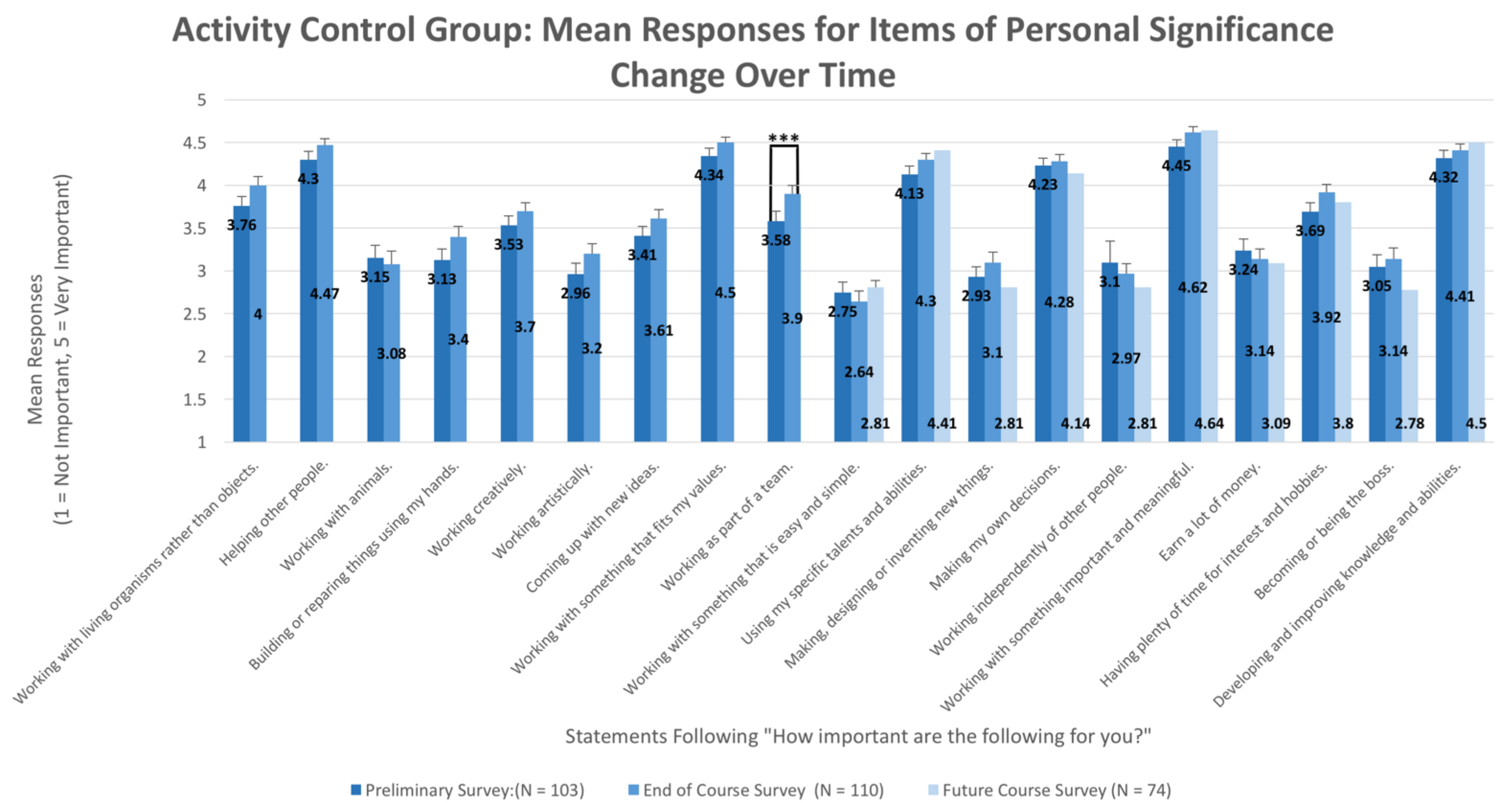

Figure 78: Change over time in mean responses for items of personal significance, activity control group with error bars for the standard error of the mean

There were no significant differences found amongst mean responses for items of personal significance in the intervention group, however the mean responses over time can be seen in figure 79 below.

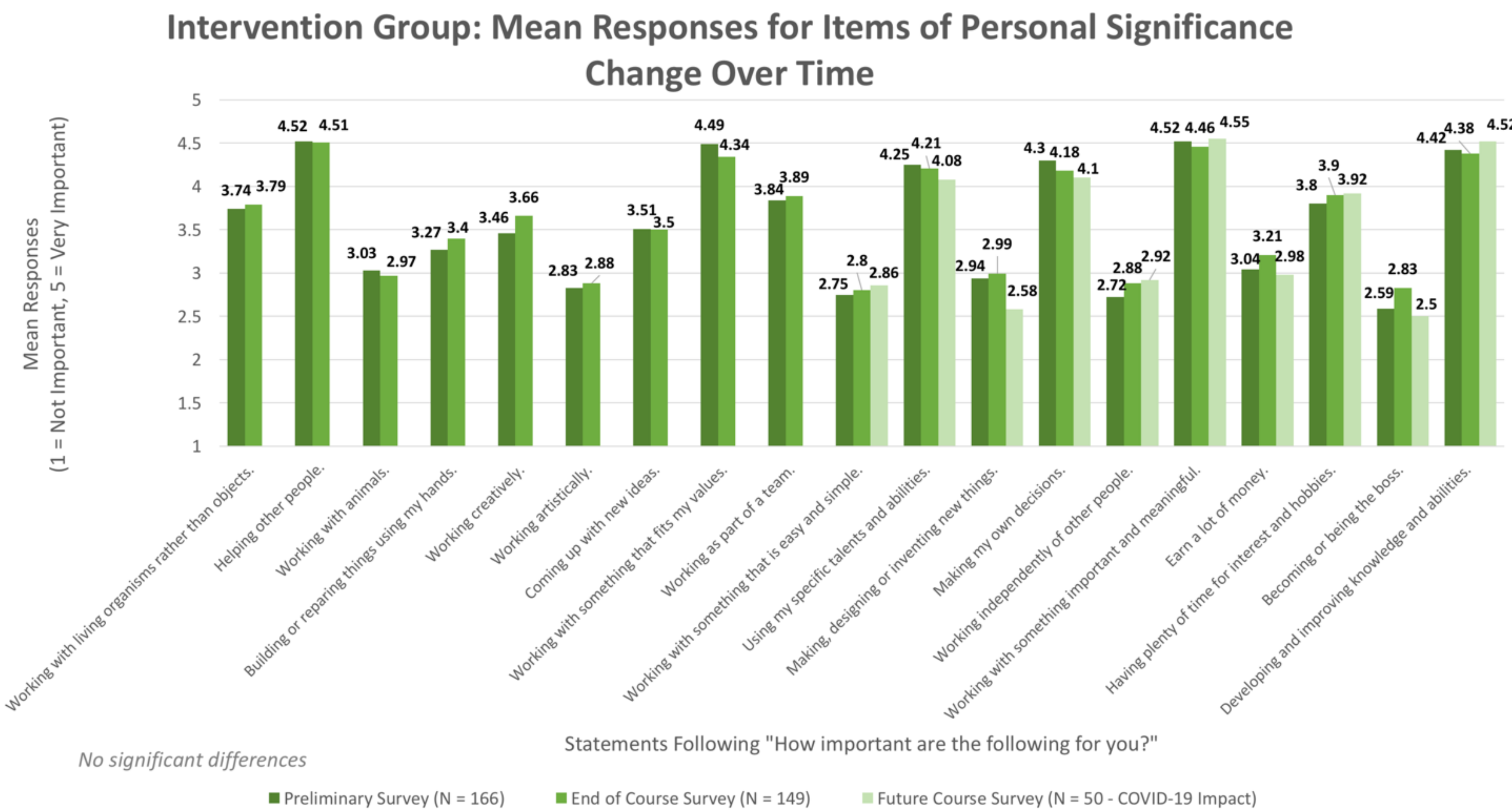

Figure 79: Change over time in mean responses for items of personal significance, intervention group with error bars for the standard error of the mean

5.1.6.4 Life Science Courses' Impact

Mean responses from the control group for items designed to evaluate the impact of life science courses indicated only one significant difference. This difference was a significant increase in the perceived value of the things students learn in life sciences courses to everyday life from the preliminary survey to the end of courses survey (p = 0.0339) and from the preliminary survey to the future course survey (p = 0.0012). This change over time can be seen in figure 80 below.

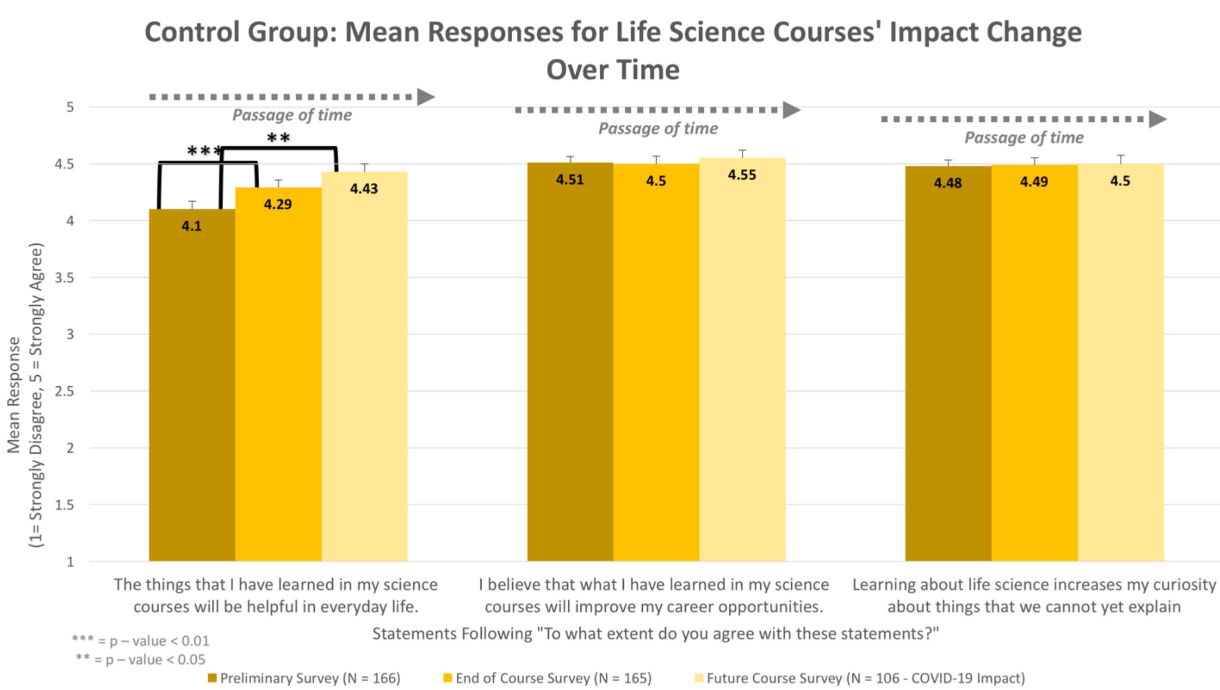

Figure 80: Change over time in mean responses for life science courses' impact, control group with error bars for the standard error of the mean

In contrast to results from the control group, mean responses from the activity control group for items designed to evaluate the impact of life science courses indicated significant differences in all three items. Similar to the control group, the results for this group indicate a significant increase in perceived value of the things students learn in life sciences courses to everyday life from the preliminary survey to the end of courses survey and from the preliminary survey to the future course survey (p <0.0001 for both). The same significant increases were found amongst responses regarding the value of the things learned in life science courses for future career opportunities and for increasing curiosity in things we cannot yet explain. This change over time can be seen in figure 81 below.

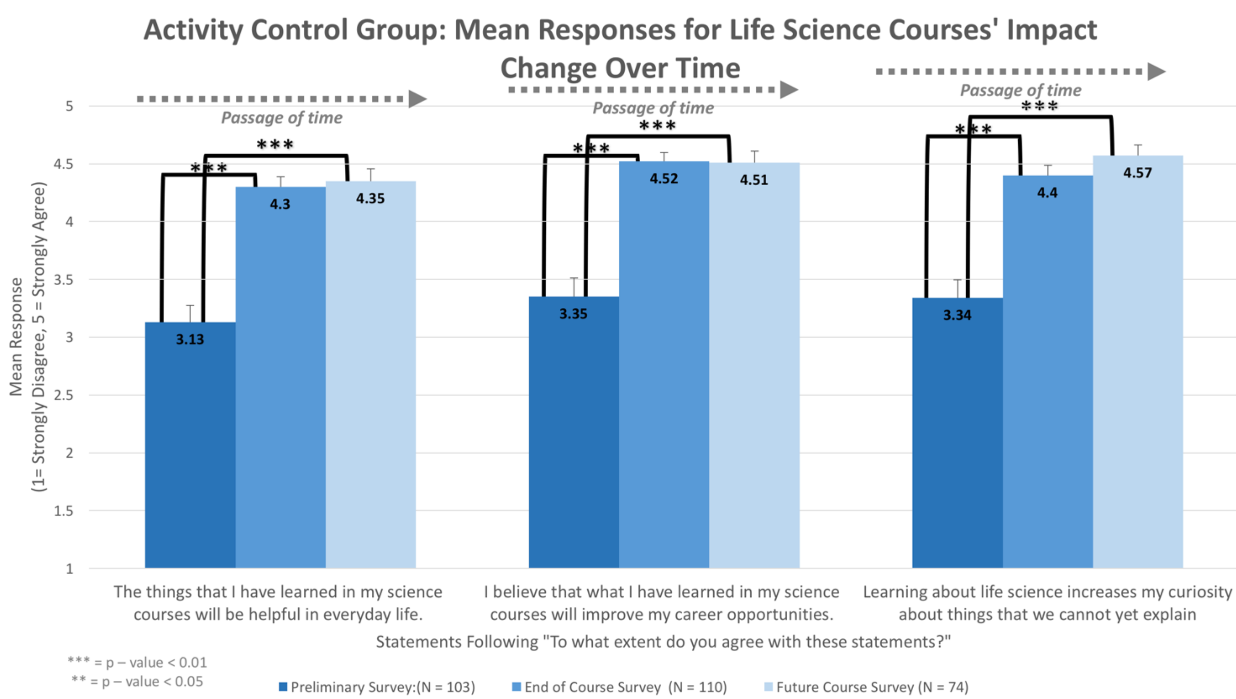

Figure 81: Change over time in mean responses for life science courses' impact, activity control group with error bars for the standard error of the mean

Similar to the control group, mean responses from the intervention group for items designed to evaluate the impact of life science courses indicated only one significant difference. However, this significant difference was in the increase in curiosity caused by learning the life sciences from the end of course survey to the future course survey (p = 0.0114). This change over time can be seen in figure 82 below.

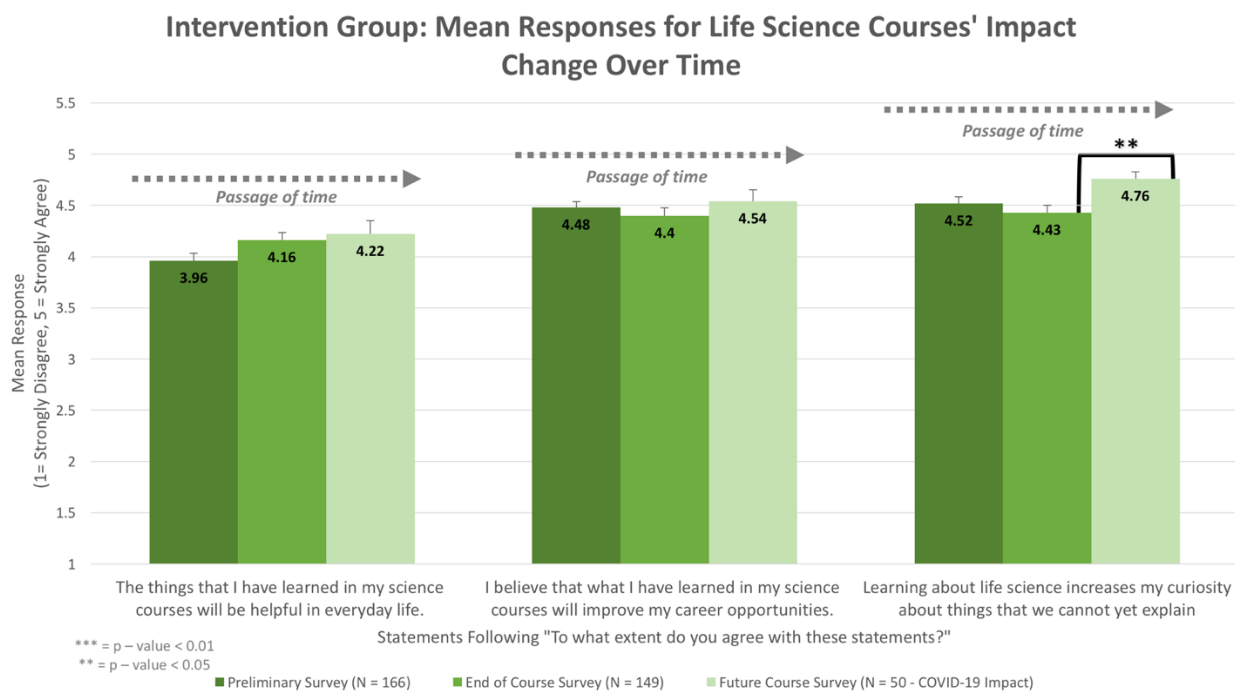

Figure 82: Change over time in mean responses for life science courses' impact, intervention group with error bars for the standard error of the mean

5.1.6.5 Interest in Nature and/or Sciences Outside of the Classroom

For all groups, there was no significant difference in any of the mean responses for the item "Read about nature or science in books and magazines". However, there were varying significant differences for the item concerning how often students watched media about nature and/or science.

For the control group, mean responses indicated only one significant decrease in the amount of time that students watched media about nature and/or sciences from the preliminary survey to the end of course survey ($p = 0.0043$). This change over time can be seen in figure 83 below.

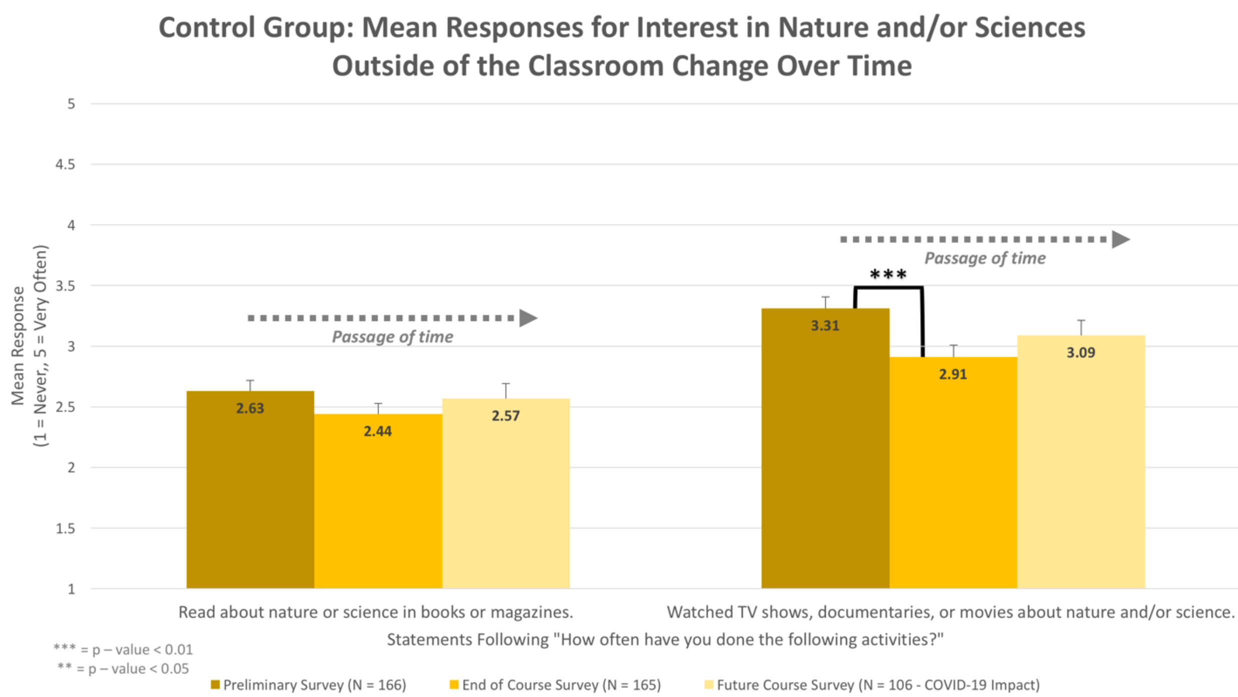

Figure 83: Change over time in mean responses for interest in nature and/or sciences outside of the classroom, control group with error bars for the standard error of the mean

There were no significant differences for mean responses to either item designed to evaluate the interests of students in nature and/or sciences outside of the classroom amongst surveys for the activity control group. There was, however, a significant decrease in the amount of time students watched media about nature and/or science within the intervention group from the preliminary survey to the end of course survey (p = 0.0018). Interestingly, there was also a significant increase for this same item within the intervention group from the end of course survey to the future course survey (p = 0.012). This change over time for the intervention group, and changes in means over time for the activity control group can be seen in figures 84 and 85 below.

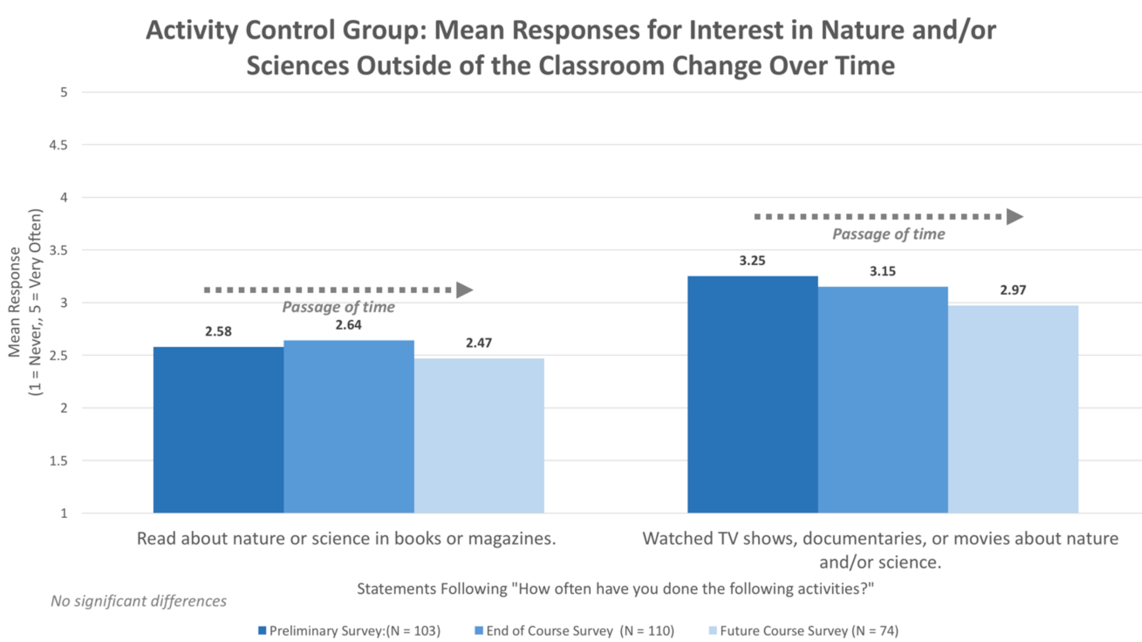

Figure 84: Change over time in mean responses for interest in nature and/or sciences outside of the classroom, activity control group

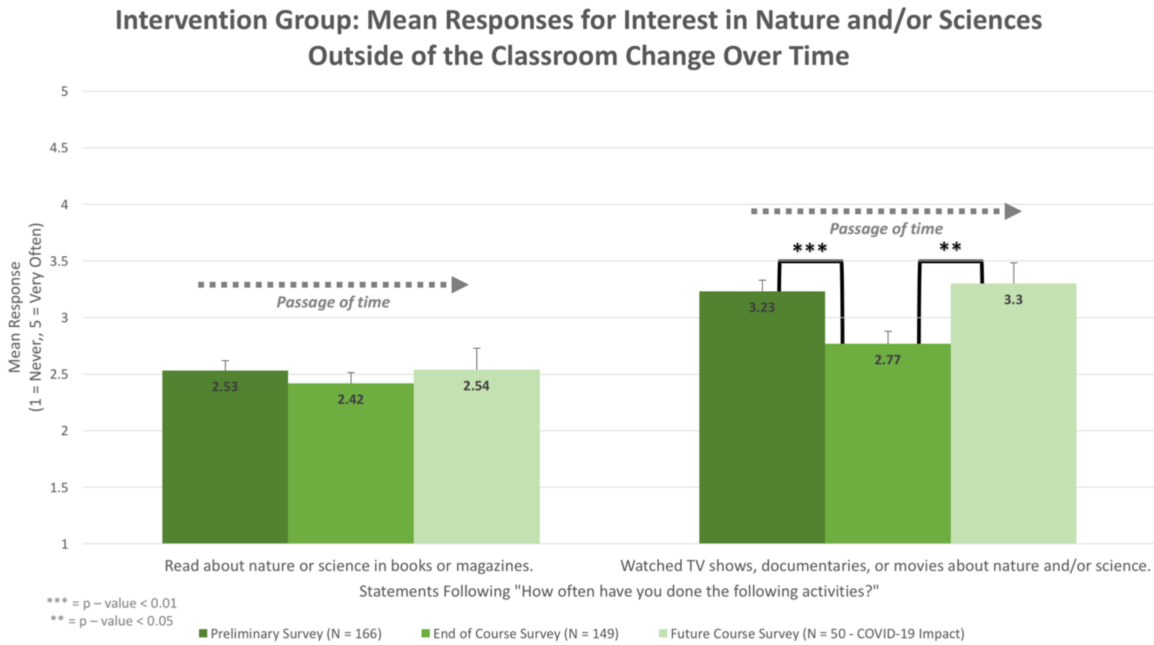

Figure 85: Change over time in mean responses for interest in nature and/or sciences outside of the classroom, intervention group with error bars for the standard error of the mean

5.1.6.6 Approaches and Attitudes for Past Courses

Items designed to evaluate students' approaches and attitudes for past courses were only included on the end of course survey and future course survey.

Mean responses from the control group for approaches and attitudes for past courses showed more change over time than the other two study groups. These responses indicated a significant decrease in the use of memorization ($p = 0.0004$), enjoyment of studying when practicing application of information ($p = 0.0123$) and the enjoyment of studying when practicing memorization ($p = 0.0253$). This change over time can be seen in figure 86 below.

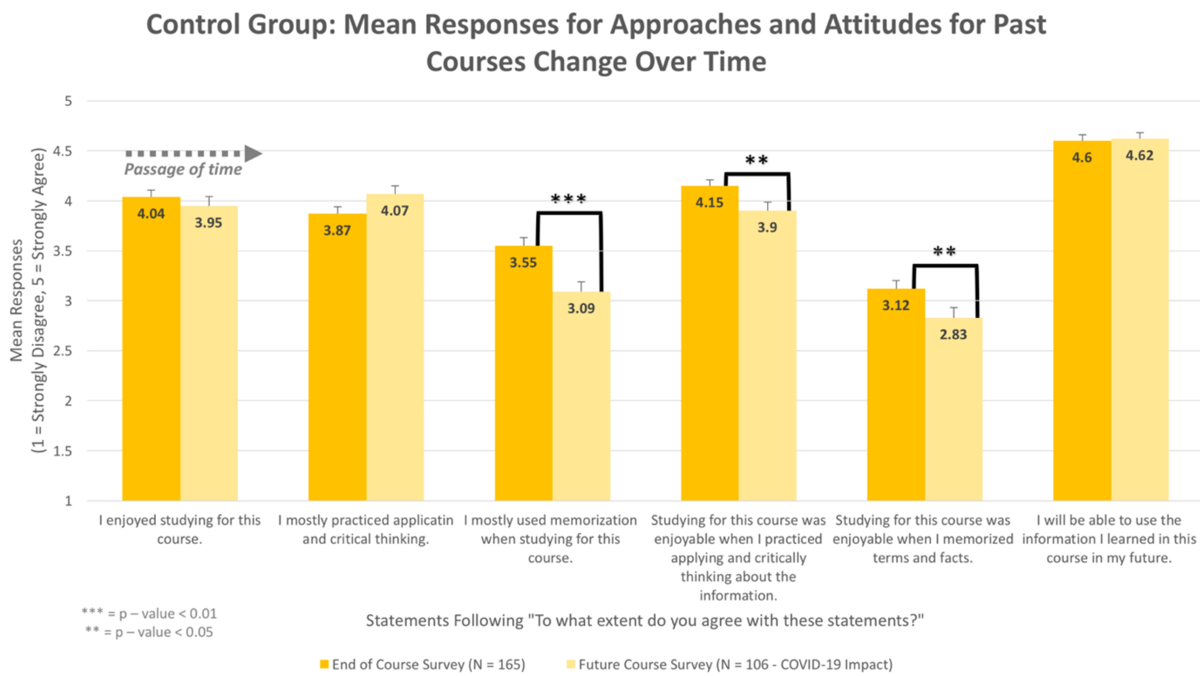

Figure 86: Change over time in mean responses for approaches and attitudes for past courses, control group with error bars for the standard error of the mean

Only one significant difference in mean responses for items designed to evaluate students' approaches and attitudes for past courses within the activity control group was identified and no significant differences within the intervention group were identified. For the activity control group, similar to the control group, results showed a significant decrease in the amount of memorization used to study ($p = 0.0002$). This change over time for the activity control group, and changes in means over time for the intervention group can be seen in figures 87 and 88 below.

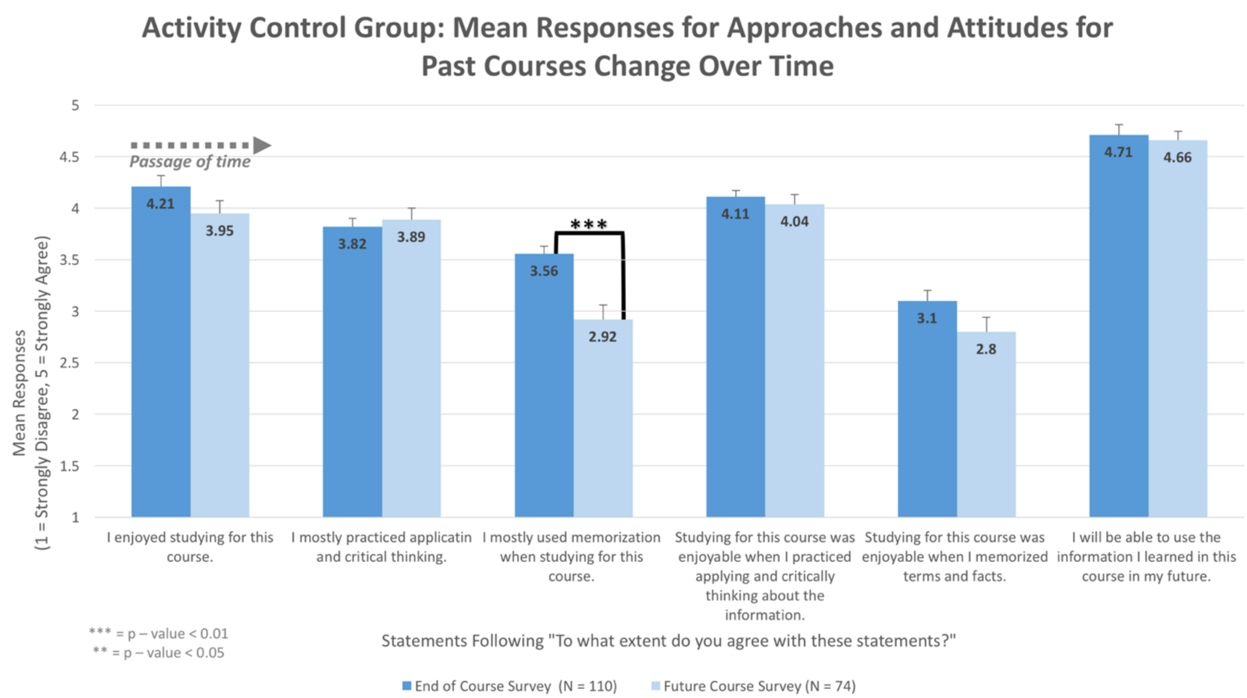

Figure 87: Change over time in mean responses for approaches and attitudes for past courses, activity control group with error bars for the standard error of the mean

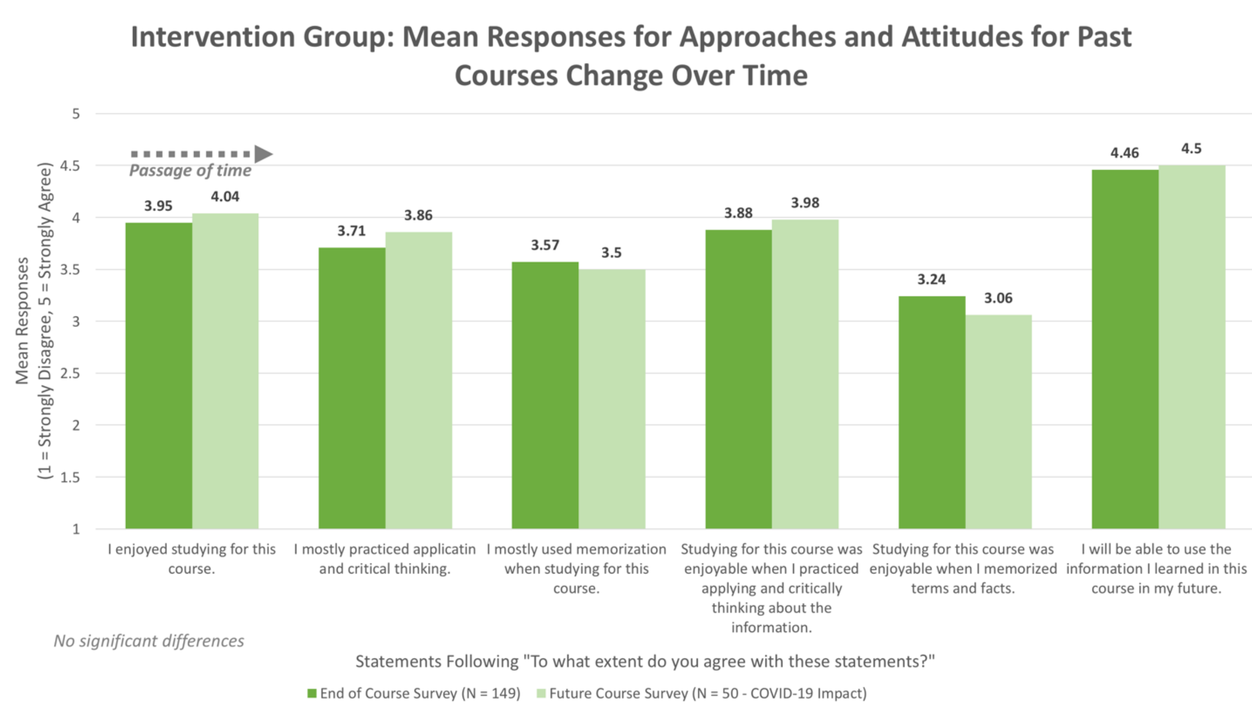

Figure 88: Change over time in mean responses for approaches and attitudes for past courses, intervention group with error bars for the standard error of the mean

5.2 Spatial Assessments

The average score on the first Anatomical Spatial Reasoning Assessment (ASRA 1) for the entire study population was 38% correct, average scores on the ASRA 2 and 3, as well as the Crystal Slicing Test for the entire study population was 41% correct, and the average score on the Revised Purdue Spatial Visualization Tests: Visualization of Rotations (PMRT-R) for the entire study population was 66% correct. For the ASRA 1, the Crystal Slicing Test and the PMRT-R, there were no significant differences found in mean scores amongst groups. However, the activity control group did perform significantly better on the ASRA 2 than both the control (p = 0.0231) and the intervention (p = 0.0043) groups. In addition, both the control group (p <0.0001) and the activity control group (p <0.0001) performed significantly better than the intervention group on the ASRA 3. These scores can be seen graphically in figure 89 below.

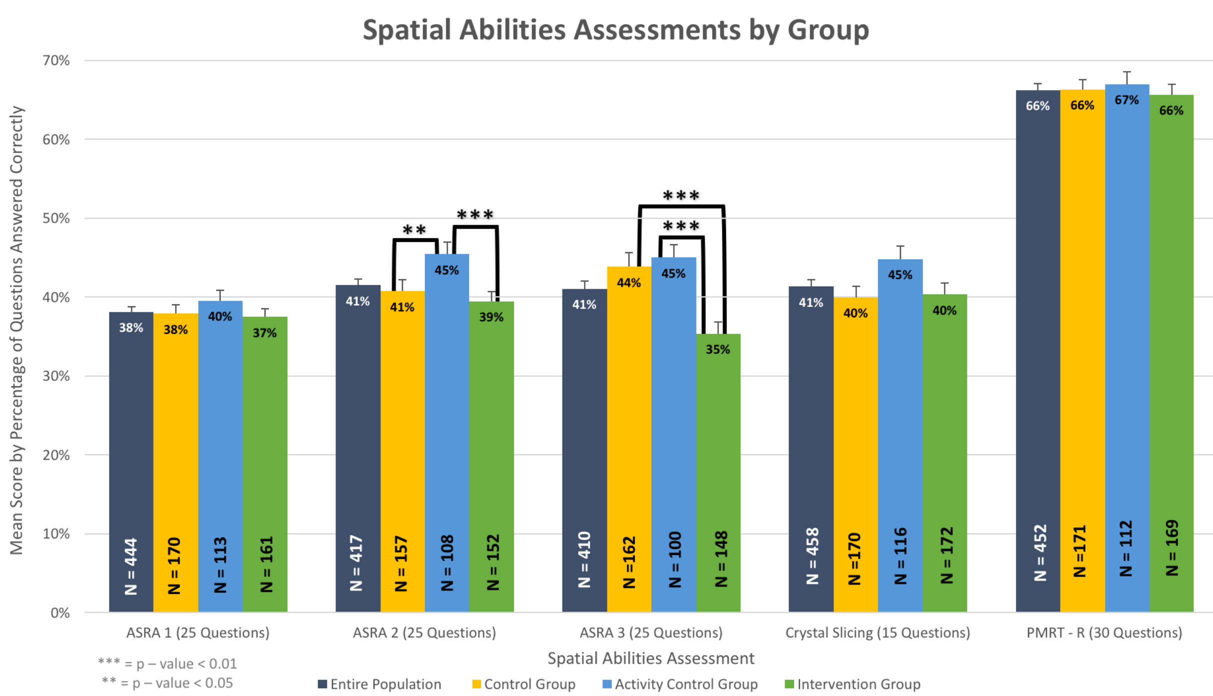

Figure 89: Spatial abilities by group showing standard error of the mean for each group

In addition to some variance in spatial ability amongst groups, average scores for the entire study population differed by gender. None of the three ASRA scores differed by gender, however, both scores for the Crystal Slicing Test and the PMRT-R showed a significantly higher score for males than for females (p <0.0001 for both). These differences and the average scores by gender can be seen in figure 90 below.

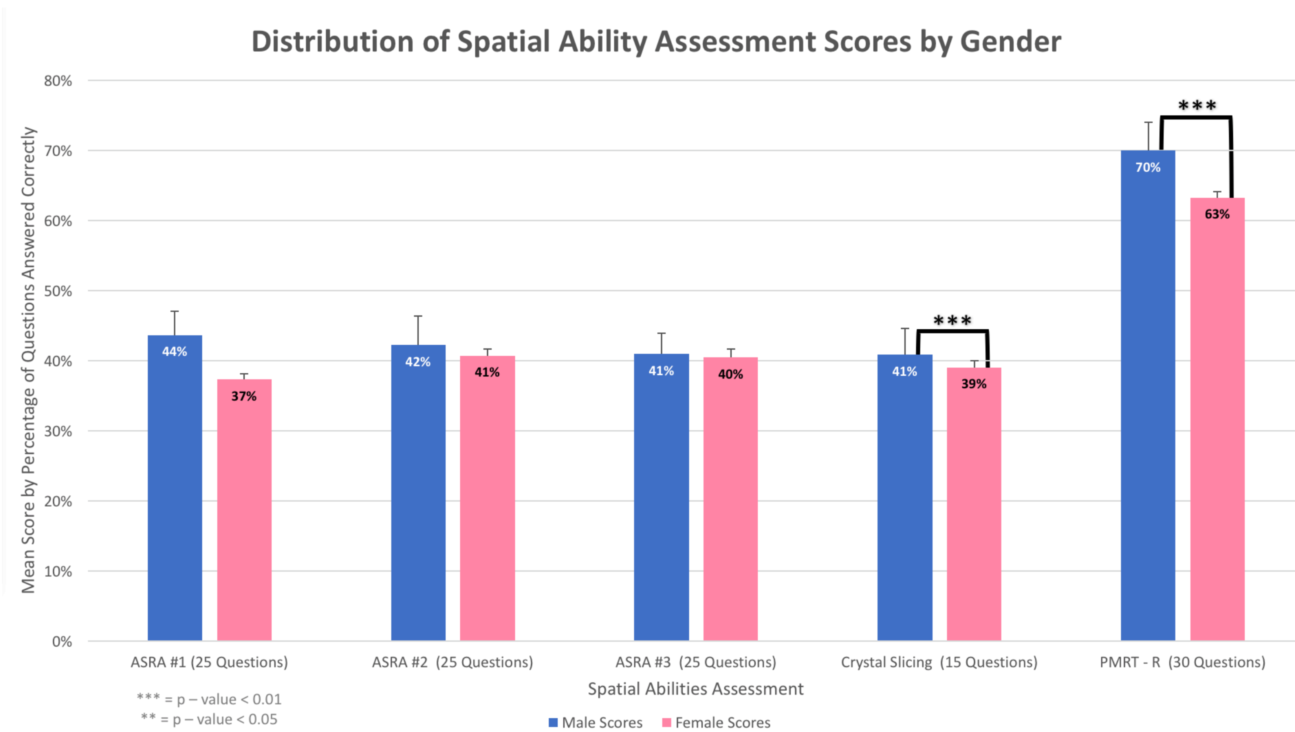

Figure 90: Distribution of spatial ability assessment scores by gender showing standard error of the mean for each group

5.2.1 Spatial Assessment Correlations to Summative Assessments for the Control Group

Many of the performance assessments and spatial ability assessments were correlated for the control group.

Thoracic Limb Myology and Basic Biomechanics Preliminary Quiz scores were positively correlated with the ASRA 2 (Rsquare = 0.0496, p = 0.0052), the Crystal Slicing Test (Rsquare = 0.0399, p = 0.0092) and the PMRT – R (Rsquare = 0.04, p = 0.009). However, the change in preliminary quiz to post quiz for the same topic was negatively correlated with the ASRA 2 (Rsquare = 0.029, p = 0.0353). These results indicate that students with a higher score on the preliminary quiz were more likely to test for higher spatial abilities on the ASRA 2, Crystal Slicing and PMRT – R tests. However, students who had a higher change in quiz score were more likely to have lower scores on the ASRA 2.

The Skeletal Muscle Histology and Physiology Preliminary quiz scores were positively correlated with ASRA 1 (Rsquare = 0.03, p = 0.0228), and PMRT – R scores (Rsquare = 0.042, p = 0.0075), indicating that students who scored higher on the preliminary quiz were more likely to have scored higher on the ASRA 1 and PMRT – R tests. However, the change in quiz score for this topic was negatively correlated with PMRT – R scores (Rsquare = 0.024, p = 0.0463), indicating that students who improved more from the preliminary quiz to the post quiz were also more likely to have scored lower on the PMRT – R.

Scores on the preliminary quiz for the peripheral nervous system were positively correlated with scores on the ASRA 1 (Rsquare = 0.034, p = 0.016), ASRA 2 (Rsquare = 0.031, p = 0.0286) and PMRT – R (Rsquare = 0.042, p = 0.0073), indicating that students who performed better on these spatial assessments also performed better on the preliminary quiz. However, results also indicate that students who had a greater improvement between quizzes for this topic were likely to have lower ASRA 1 (Rsquare = 0.027, p = 0.0345) and PMRT – R (Rsquare = 0.027, p = .0323) scores.

Scores related to the integration quizzes were only correlated to ASRA 2. Students who scored higher on the preliminary quiz for this topic were more likely to have scored higher on the ASRA 2 (Rsquare = 0.0329, p = 0.0238). However, students with a greater improvement between quizzes for this topic were more likely to have lower scores on the ASRA 2 (Rsquare = 0.0657, p = 0.0019).

Exam scores were only positively correlated with spatial assessments. Students who scored higher on the ASRA 2 (Rsquare = 0.05, p = 0.0049) and the ASRA 3 (Rsquare = 0.024, p = 0.0016) were more likely to score higher on the third laboratory exam. Students who scored higher on the ASRA 1 were more likely to score higher on the first lecture exam (Rsquare = 0.026, p = 0.0374), the second lecture exam (Rsquare = 0.0285, p = 0.0278) and the third lecture exam (Rsquare = 0.028, p = 0.0279). Students who scored higher on the ASRA 2 were more likely to score higher on the third lecture exam (Rsquare = 0.037, p = 0.016) and the final lecture exam (Rsquare = 0.047, p = 0.0064). In addition, students who scored higher on the ASRA 3 were more likely to score higher on the second lecture exam (Rsquare = 0.061, p = 0.0016) and students who scored higher on the PMRT – R were more likely to score higher on the first lecture exam (Rsquare = 0.023, p = 0.049).

A summary of the correlations between spatial assessments and performance assessments for the control group can be seen in table 12 below.

Spatial Ability Correlations to Performance Assessments by Topic and Assessment – Control Group (only performance assessment items that had correlations with spatial assessments are listed)		
Performance Assessment	**Positively Correlated Spatial Assessment**	**Negatively Correlated Spatial Assessment**
Thoracic Limb Myology and Basic Biomechanics		
Preliminary Quiz	*ASRA 2*	*none*
	Crystal Slicing Test	
	PMRT - R	
Change in Quiz Score	*none*	*ASRA 2*
Skeletal Muscle Histology and Physiology		
Preliminary Quiz	*ASRA 1*	*none*
	PMRT – R	
Change in Quiz Score	*none*	*PMRT– R*
The Peripheral Nervous System		
Preliminary Quiz	*ASRA 1*	*none*
	ASRA 2	
	PMRT – R	
Change in Quiz Score	*none*	*PMRT – R*
		ASRA 1
Integration		
Preliminary Quiz	*ASRA 2*	*none*
Change in Quiz Score	*none*	*ASRA 2*
Laboratory Exam Scores		
Exam #3	*ASRA 2*	*none*
	ASRA 3	
Lecture Exam Scores		
Exam #1	*ASRA 1*	*none*
	PMRT – R	
Exam #2	*ASRA 1*	
	ASRA 3	
Exam #3	*ASRA 1*	
	ASRA 2	
Final Exam	*ASRA 2*	

Table 12: Spatial ability correlations to performance assessments by topic and assessment for the control group

5.2.2 Spatial Assessment Correlations to Summative Assessments for the Activity Control Group

Like the control group, many of the performance assessments and spatial ability assessments were correlated for the activity control group.

Both the preliminary (Rsquare = 0.0495, p = 0.0261) and post intervention (Rsquare = 0.065, p = 0.0106) quizzes for thoracic limb myology and basic biomechanics were positively correlated with scores on the ASRA 3, indicating that students who scored higher on the ASRA 3 were more likely to perform better on quizzes with this topic. Students who performed better on the PMRT – R were also more likely to perform better on the post quiz for this topic (Rsquare = 0.061, p = 0.0085).

There were no correlations between the quiz scores for skeletal muscle histology and physiology and the spatial assessments. However, results did indicate that students who performed better on the preliminary quiz for the peripheral nervous system were also more likely to have performed better on the ASRA 1 (Rsquare = 0.039, p = 0.0348).

Results also indicated that students who performed better on any of the ASRAs or the PMRT – R were more likely to perform better on the preliminary integration quiz (ASRA 1; Rsquare = 0.0535, p = 0.0137, ASRA 2; Rsquare = 0.0978, p = 0.001, ASRA 3; Rsquare = 0.046, p = 0.0319, PMRT – R; Rsquare = 0.036, p = 0.0463). However, results for this topic also indicated that students who had greater improvement between quizzes were more likely to have lower scores on both the ASRA 1 (Rsquare = 0.041, p = 0.032) and the ASRA 2 (Rsquare = 0.0426, p = 0.0322).

Again, exam scores had no negative correlations to any of the spatial assessment scores. Students who performed better on the ASRA 1 were more likely to perform better on the first laboratory exam (Rsquare = 0.055, p = 0.0127), the first lecture exam (Rsquare = 0.078, p = 0.0027) and the third lecture exam (Rsquare = 0.0398, p = 0.0342). Likewise, students who performed better on the ASRA 2 were more likely to perform better on the first laboratory exam (Rsquare = 0.085, p = 0.0022) and the final lecture exam (Rsquare = 0.0466, p = 0.0249).

A higher score on the ASRA 3 indicated a higher score on the first laboratory exam (Rsquare = 0.052, p = 0.0227), the first lecture exam (Rsquare = 0.069, p = 0.0084), the second lecture exam (Rsquare = 0.051, p = 0.0242), and the final lecture exam (Rsquare = 0.056, p = 0.0176). Finally, a higher score on the PMRT – R indicated higher scores on the first laboratory exam (Rsquare = 0.041, p = 0.0332), the first lecture exam (Rsquare = 0.065, p = 0.0065), the second lecture exam (Rsquare = 0.04, p = 0.0337), the third lecture exam (Rsquare = 0.04, p = 0.0337), and the final lecture exam (Rsquare = 0.036, p = 0.0457).

A summary of the correlations between spatial assessments and performance assessments for the activity control group can be seen in table 13 below.

Spatial Ability Correlations to Performance Assessments by Topic and Assessment – Activity Control Group *(only performance assessment items that had correlations with spatial assessments are listed)*		
Performance Assessment	**Positively Correlated Spatial Assessment**	**Negatively Correlated Spatial Assessment**
Thoracic Limb Myology and Basic Biomechanics		
Preliminary Quiz	*ASRA 3*	*none*
Post Intervention Quiz	*PMRT – R*	
	ASRA 3	
The Peripheral Nervous System		
Preliminary Quiz	*ASRA 1*	*none*
Integration		
Preliminary Quiz	*ASRA 1*	*none*
	ASRA 2	
	ASRA 3	
	PMRT – R	
Change in Quiz Score	*none*	*ASRA 1*
		ASRA 2
Laboratory Exam Scores		
Exam #1	*ASRA 1*	*none*
	ASRA 2	
	ASRA 3	
	PMRT – R	
Lecture Exam Scores		
Exam #1	*ASRA 1*	*none*
	ASRA 3	
	PMRT - R	
Exam #2	*ASRA 1*	
	ASRA 3	
	PMRT - R	
Exam #3	*PMRT – R*	
Final Exam	*ASRA 2*	
	ASRA 3	
	PMRT – R	

Table 13: Spatial ability correlations to performance assessments by topic and assessment for the activity control group

5.2.3 Spatial Assessment Correlations to Summative Assessments for the Intervention Group

For the intervention group, many performance assessments and spatial ability assessments were again correlated.

Students were more likely to perform better on the Thoracic Limb Myology and Basic Biomechanics Preliminary Quiz if they performed better on the ASRA 2 (Rsquare = 0.055, p = 0.004), the ASRA 3 (Rsquare = 0.165, p <0.0001), the Crystal Slicing Test (Rsquare = 0.0447, p = 0.0061), and the PMRT – R (Rsquare = 0.058, p = 0.0019). However, students who performed well on the ASRA 2 (Rsquare = 0.0294, p = 0.0461) and ASRA 3 (Rsquare = 0.0736, p = 0.0015), were more likely to have less change between their quiz scores for the same topic.

Students who performed better on the PMRT – R were more likely to perform better on both the preliminary (Rsquare = 0.03, p = 0.0268) and post intervention (Rsquare = 0.03, p = 0.0357) quizzes on the topic of skeletal muscle histology and physiology.

Scores on the Peripheral Nervous System Preliminary Quiz were positively correlated with both scores on the ASRA 3 (Rsquare = 0.0406, p = 0.0166) and scores on the PMRT – R (Rsquare = 0.0273, p = 0.038), indicating that students who performed better on these spatial exams also performed better on the preliminary quiz. In contrast, students who performed well on the ASRA 3 were less likely to perform well on the post quiz on the same topic (Rsquare = 0.037, p = 0.0225) and less likely to improve between quizzes (Rsquare = 0.084, p = 0.0005).

For quizzes involving integration of the material, students were more likely to perform better on the preliminary quiz if they had performed well on the ASRA 3 (Rsquare = 0.04, p = 0.0167) and Crystal Slicing Test (Rsquare = 0.054, p = 0.0029). However, students were less likely to improve between quizzes if they had performed better on the ASRA 3 (Rsquare = 0.032, p = 0.033), the Crystal Slicing Test (Rsquare = 0.027, p = 0.0368) and the PMRT – R (Rsquare = 0.037, p = 0.0152).

Finally, students who performed better on the ASRA 3 were more likely to perform better on the first lab exam (Rsquare = 0.038, p = 0.0179), the first lecture exam (Rsquare = 0.0326, p = 0.0323), the second lecture exam (Rsquare = 0.046, p = 0.0105), the third lab exam (Rsquare = 0.036, p = 0.0217), the third lecture exam (Rsquare = 0.069, p = 0.0016), and the final lecture exam (Rsquare = 0.062, p = 0.0029). Students who performed well on the PMRT – R were also more likely to perform well on the first lecture exam (Rsquare = 0.036, p = 0.0166), and students who performed well on the Crystal Slicing Test were more likely to perform well on the second lecture exam (Rsquare = 0.0424, p = 0.0088). A summary of the correlations between spatial assessments and performance assessments for the intervention group can be seen in table 14 below.

Spatial Ability Correlations to Performance Assessments by Topic and Assessment – Intervention Group *(only performance assessment items that had correlations with spatial assessments are listed)*		
Performance Assessment	**Positively Correlated Spatial Assessment**	**Negatively Correlated Spatial Assessment**
Thoracic Limb Myology and Basic Biomechanics		
Preliminary Quiz	*ASRA 2* *ASRA 3* *Crystal Slicing Test* *PMRT – R*	*none*
Change in Quiz Score	*none*	*ASRA 2* *ASRA 3*
Skeletal Muscle Histology and Physiology		
Preliminary Quiz	*PMRT – R*	*none*
Post Intervention Quiz	*PMRT – R*	*none*
The Peripheral Nervous System		
Preliminary Quiz	*ASRA 3* *PMRT – R*	*none*
Post Intervention Quiz	*none*	*ASRA 3*
Change in Quiz Score	*none*	*ASRA 3*
Integration		
Preliminary Quiz	*ASRA 3* *Crystal Slicing Test*	*none*
Change in Quiz Score	*none*	*ASRA 3* *Crystal Slicing Test* *PMRT – R*
Laboratory Exam Scores		
Exam #1	*ASRA 3*	*none*
Lecture Exam Scores		
Exam #1	*ASRA 3* *PMRT – R*	*none*
Exam #2	*ASRA 3* *Crystal Slicing*	*none*
Exam #3	*ASRA 3*	*none*
Final Exam	*ASRA 2* *ASRA 3*	*none*

Table 14: Spatial ability correlations to performance assessments by topic and assessment for the intervention group

5.3 Summative Assessments

5.3.1 Thoracic Limb Myology and Basic Biomechanics

Scores from the preliminary quiz to the post quiz within the topic of thoracic limb myology and basic biomechanics improved significantly for all three study groups. Quiz scores improved by 0.91 points in the control group (p <0.0001), by 0.44 points in the activity control group (p = 0.0024), and by 0.92 points in the intervention group (p <0.0001). None of the preliminary quiz scores amongst groups were significantly different from each other, but the post quiz score for the activity control group was significantly lower than both the control (p = 0.0307) and the intervention (p = 0.0015) post quiz scores. The improvement in quiz score was, therefore, significantly lower for the activity control group than for both the control (p = 0.0205) and the intervention groups (p = 0.0236). However, there was no significant difference between the improvement of quiz score for the intervention and control groups. These results are represented graphically in figure 91 below.

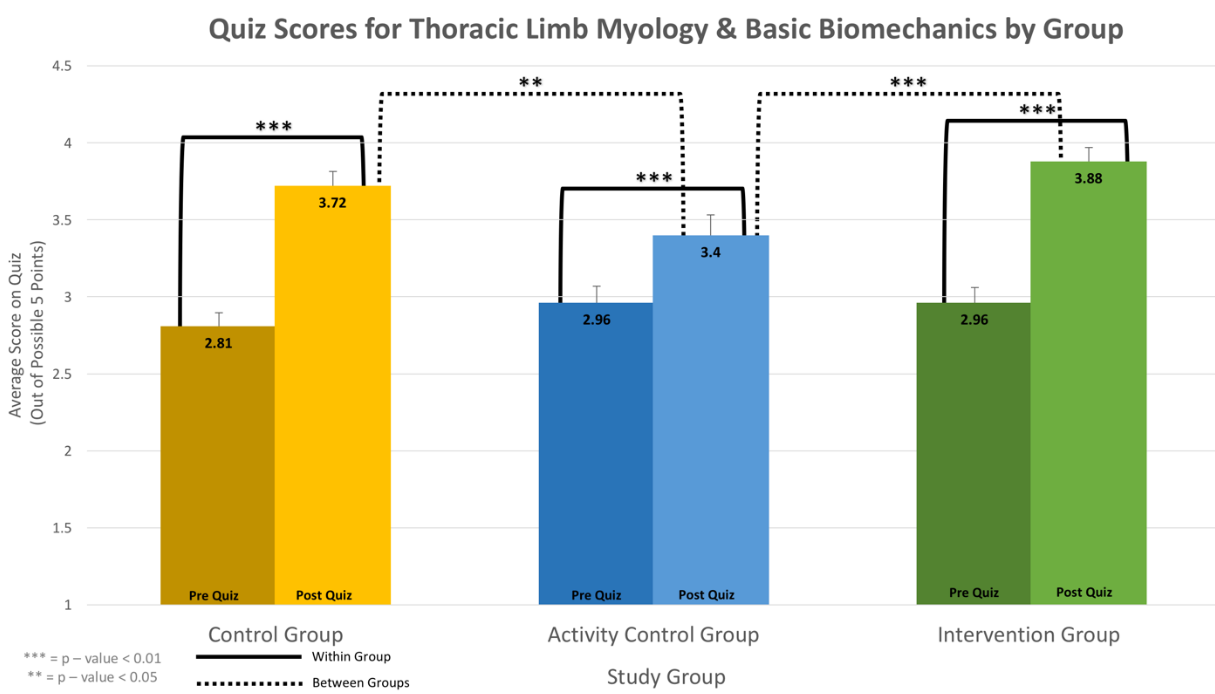

Figure 91: Quiz scores for thoracic limb myology and basic biomechanics by group with error bars for the standard error of the mean

5.3.2 Skeletal Muscle Histology and Physiology

Scores from the preliminary quiz to the post quiz within the topic of skeletal muscle histology and physiology did not improve significantly for any of the three study groups. Interestingly, quiz scores for both the activity control and intervention groups decreased. Quiz scores improved by 0.23 points in the control group, but decreased by 0.11 points in the activity control group, and decreased by 0.04 points in the intervention group. None of the preliminary quiz scores or the post quiz scores were significantly different amongst groups, nor were any of the changes in quiz scores. These results are represented graphically in figure 92 below.

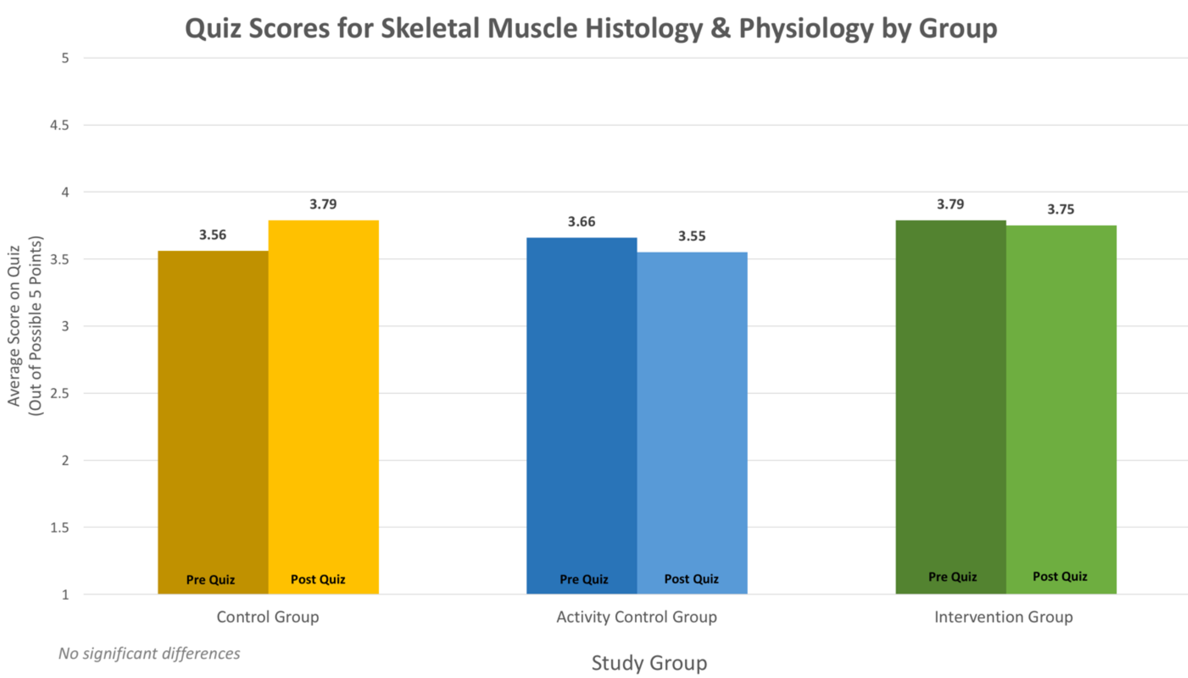

Figure 92: Quiz scores for skeletal muscle histology and physiology by group

5.3.3 The Peripheral Nervous System

Scores from the preliminary quiz to the post quiz within the topic of the peripheral nervous system improved significantly for both the control (p <0.0001) and intervention (p <0.0001) groups. Quiz scores improved by 0.65 points in the control group, by 0.33 points in the activity control group, and by 0.92 points in the intervention group. The preliminary quiz score for the activity control group was significantly higher than the preliminary quiz score for the intervention group (p = 0.0085), but none of the post quiz scores for this topic differed significantly amongst groups. The improvement in quiz score was, however, significantly higher for the intervention group than for the activity control group (p = 0.003). However, there was no significant difference between the improvement of quiz score for the intervention and control groups. These results are represented graphically in figure 93 below.

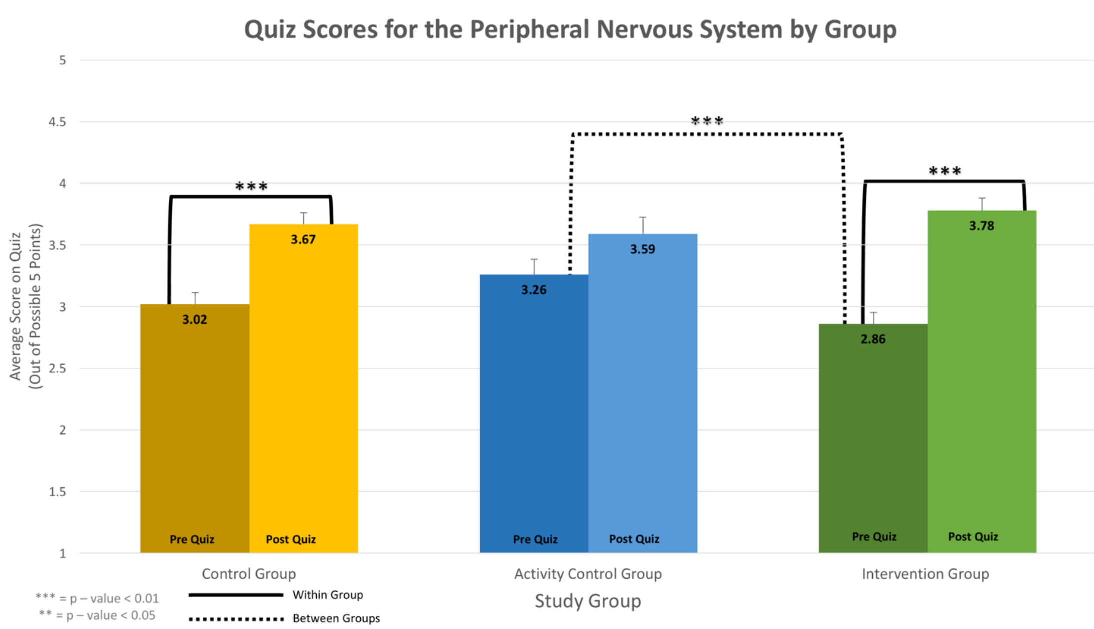

Figure 93: Quiz scores for the peripheral nervous system by group with error bars for the standard error of the mean

5.3.4 Integration

Scores from the preliminary quiz to the post quiz for quizzes involving integration of topics improved significantly for all three groups. Quiz scores improved by 0.86 points in the control group ($p < 0.0001$), by 1.39 points in the activity control group ($p < 0.0001$), and by 0.98 points in the intervention group ($p < 0.0001$). The preliminary quiz score for the control group was significantly higher than the preliminary quiz scores for both the intervention ($p = 0.0366$) and activity control ($p = 0.0015$) groups. The preliminary quiz score for the activity control group was also significantly lower than the intervention group ($p < 0.0001$). However, none of the post quiz scores for this topic differed significantly amongst groups. The improvement in quiz score was, however, significantly higher for the activity control group than for both the intervention ($p = 0.0114$) and control ($p = 0.0015$) groups. However, there was again no significant difference between the improvement of quiz score for the intervention and control groups. These results are represented graphically in figure 94 below.

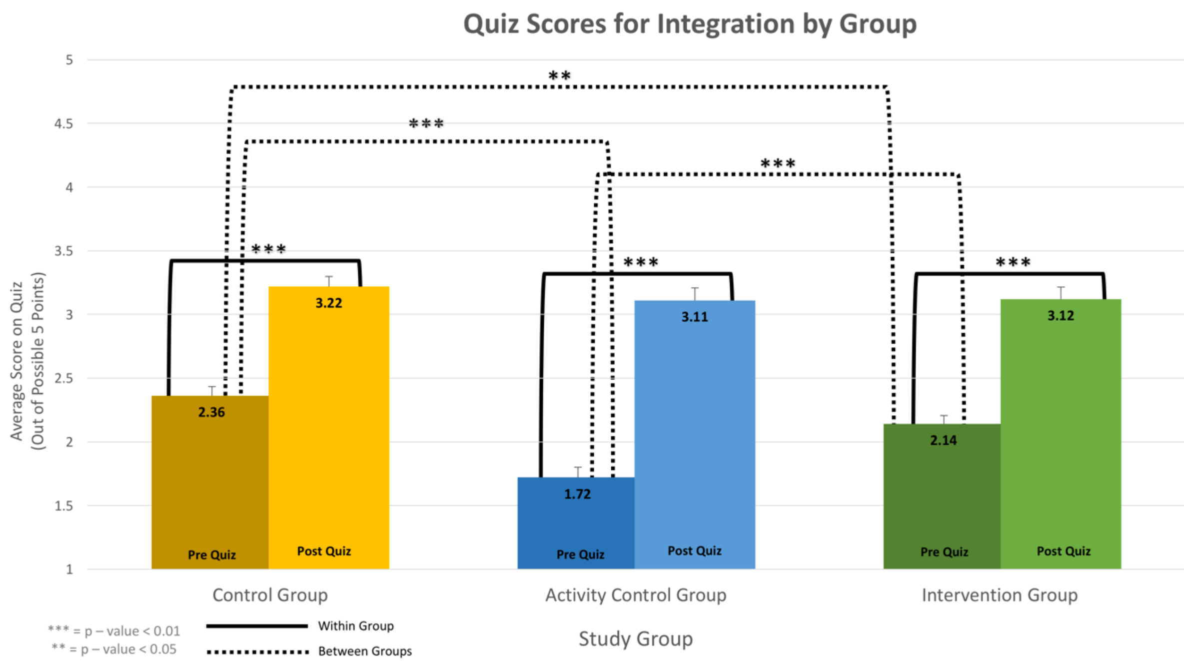

Figure 94: Quiz scores for integration by group with error bars for the standard error of the mean

5.3.5 Course Exams

Laboratory exam scores did not differ significantly amongst groups for the first exam. However, the intervention group did score significantly lower on the second ($p = 0.0001$), third ($p < 0.0001$) and final ($p < 0.0001$) exams compared to the control group. The activity control group also scored significantly lower on the final exam compared to the control group ($p = 0.0078$). Interestingly, the activity control group scored significantly higher on the third exam than both the control ($p = 0.0107$) and intervention ($p < 0.0001$) groups. These results are represented graphically in figure 95 below.

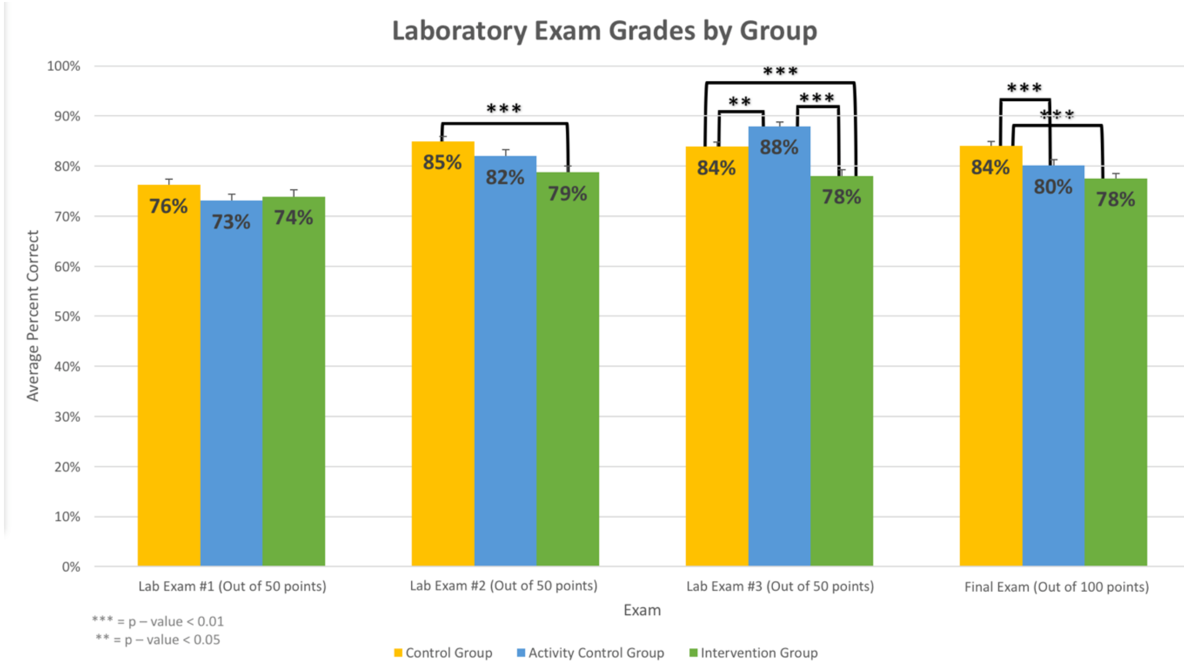

Figure 95: Laboratory exam grades by group with error bars for the standard error of the mean

Lecture exam grades, like laboratory exam grades, did not differ significantly for the first exam. However, the intervention group again scored lower than both the control ($p < 0.0001$) and the activity control ($p < 0.0001$) groups on the second exam. There were no significant differences amongst groups again for the third exam, but both the activity control ($p = 0.0008$) and the intervention ($p = 0.0133$) groups scored lower than the control group on the final exam. These results are represented graphically in figure 96 below.

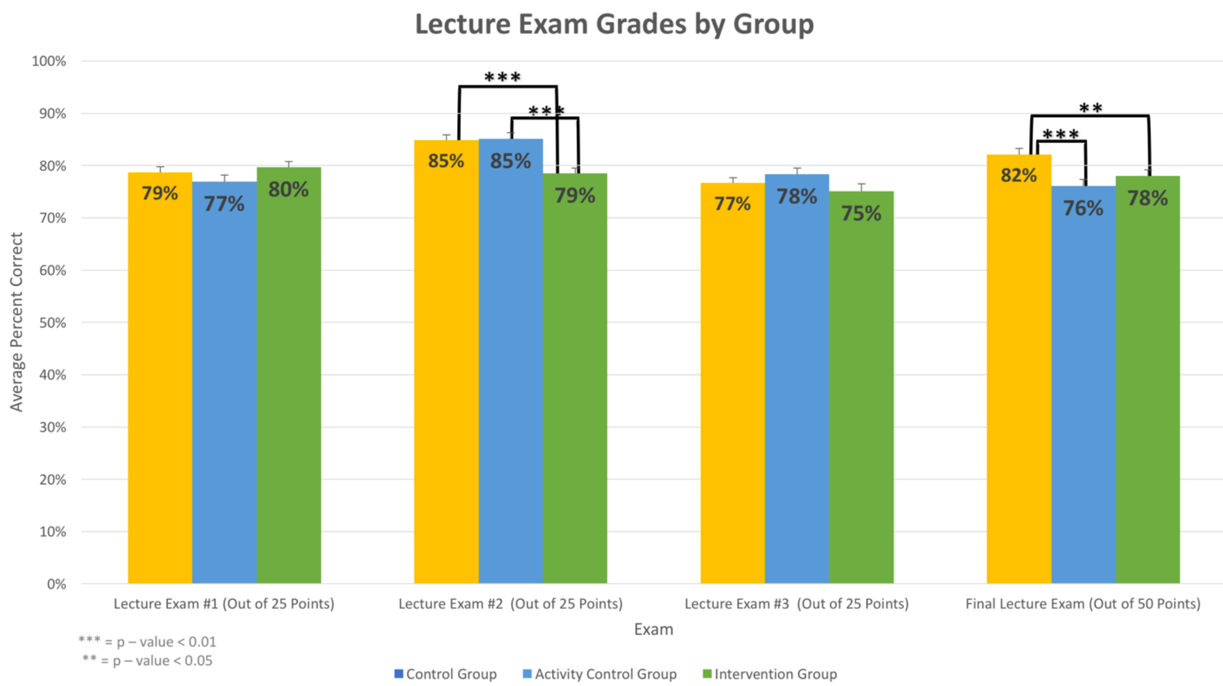

Figure 96: Lecture exam grades by group with error bars for the standard error of the mean

6 CONCLUSIONS

6.1 Hypothesis #1: Attitudes Towards Learning

"Engaging with a physically interactive model will have a positive and sustained influence on students' attitudes towards learning, including their source of motivation (i.e. internal vs. external)."

6.1.1 Research Outcomes

- *To determine the extent to which supplemental instruction with a physically interactive model will affect students' attitude toward learning life sciences.*
    - *To determine whether this effect is positive or negative.*

      Attitudes towards learning the life sciences for students who had supplemental instruction with a physically interactive model seemed to be positively affected. However, this positive shift in attitudes towards learning the life sciences was also seen without the supplemental instruction of a physically interactive model.

      - *Attitudes and Motivations for Education – Preliminary Survey*

        Results from the preliminary survey indicate that students in the control group and in the intervention group came into the course already possessing a relatively positive attitude towards studying and learning in the life sciences as compared to the attitudes of the activity control group.

        Again, in regard to the impact students perceived from their life science courses, the control and intervention groups had a significantly more favorable response compared to the activity control group. It is, however, important to note that the most chosen response for both the item concerning career opportunities and the item concerning curiosity were "strongly agree" for all three groups, indicating that most students in all three groups placed a high value on what they learn in their life sciences courses.

Considering all responses from the preliminary survey, it seems that students in the control group and intervention group began the course with a generally positive attitude towards learning the life sciences, whereas students in the activity control group had a significantly more negative attitude.

- *Attitudes and Motivations for Education – End of Course (Final) Survey*

The end of course survey results revealed that students in the activity control group placed significantly more value on the information learned during the Biomedical Anatomy course compared to the intervention group.

Considering the control group independently, students' enjoyment of both studying and learning in the life sciences was rated higher than at the beginning of the course.

Students in the activity control group rated their enjoyment of learning and studying in the life sciences as well as their enjoyment of learning in general significantly higher.

Students in the intervention group, similar to the other two groups, rated their enjoyment of studying in the life sciences higher at the end of the semester. Although it was not a significant change, these students also had higher rating in regard to their enjoyment of learning the life sciences and learning in general.

Students in all groups continued to place a high value on the impact of their life sciences courses. Specifically, both the control group and the activity control group placed a significantly higher perception of the things they have learned in their life sciences courses regarding their impact on everyday life as compared to the beginning of the course. The activity control group also saw significant improvements in their perception of life science courses' impact regarding their career opportunities and curiosity. Students in the intervention group, however, did not report any significant changes in their perception of the impact of their life sciences courses.

Based on their responses to survey items, students in all three study groups had more positive attitude towards learning the life sciences based by the end of the semester. Both the intervention and control gained more positive attitudes. The previously negative attitude of the activity control group seemed to make a drastic shift throughout the semester and, by the end of the semester, was overall positive.

To determine whether any change in students' attitudes towards learning after engaging with the physically interactive model is retained throughout the remainder of the students' undergraduate career.

The changes made in students' attitudes towards learning after engaging with the physically interactive model were retained and became more favorable throughout the remainder of the students' undergraduate career. However, this retention and increasingly favorable response was also seen in students who did not have supplemental instruction with a physically interactive model.

- *Attitudes and Motivations for Education – Future Course Survey*

At the conclusion of the second semester of the study, students in the activity control group reported that they enjoyed learning life sciences significantly more than the control group, but only very slightly more than the intervention group.

Students in the control group had significantly more positive responses than at the beginning of the first semester as well as at the end of the semester. However, they also experienced a significant decrease in the amount of enjoyment they experienced in learning life sciences specifically compared to the end of the first semester.

The activity control group rated their enjoyment of studying and learning (both specifically for life science courses and in general) higher compared to than they had for the same activities at the beginning of the first semester of the study.

Like the activity control, students in the intervention group also rated their enjoyment of learning in general significantly higher when compared to the beginning of the first semester of the study. These students also rated their enjoyment for studying the life sciences specifically higher than they had at both the beginning and the end of the first semester.

Results from the future course survey indicate that all three groups maintained a positive attitude towards learning the life sciences throughout the remainder of their undergraduate career. However, the activity control and intervention groups gained even more positive attitudes, whereas the control group’s remained relatively the same.

- *To determine the extent to which providing alternative methods and approaches to material in life sciences will affect students' source of motivation.*
    - *To determine whether this effect is positive or negative.*

      Students' source of motivation was positively affected (moved toward intrinsic motivation) immediately after being provided with alternative methods and approaches to the material in the form of a physically interactive model. However, the effect was not sustained consistently throughout the course.

        - *Attitudes and Motivations for Education – Preliminary Survey*

          Preliminary survey results indicate that all students were not so interested in the life sciences (i.e. nature and/or science) to spend time outside of the classroom reading or watching media about them.

          Students in all three groups placed value on helping other people, although the value that the activity control group placed on this was significantly lower than the other two groups. Students in all three groups also considered working with something important and meaningful and that fits their values important to them, whereas earning a lot of money and becoming or being the boss were less important. All students also placed value on developing and improving their knowledge and abilities. It is important to note, however, that both the activity control group and the control group placed more importance on becoming or being the boss relative to the intervention group.

          When asked to rank the most important goals, the majority of students in both the control and the intervention group ranked "Get an 'A'" above all other goals. However, the majority of students in the activity control group ranked "Learn the material" above all other goals.

Students in all three groups did not seem to have adequate intrinsic motivation in regard to learning the life sciences to study them outside of class. However, based on what students chose as personally significant to them, all groups were generally more motivated by intrinsic factors rather than extrinsic factors. Interestingly though, students in the activity control group did begin the course with more intrinsic motivation specifically regarding their goals for the course (chose "Learn the material" as their primary goal), whereas students in the control and intervention groups were more extrinsically motivated by grades (chose "Get an 'A'" as their primary goal).

- *Post Intervention Survey*

Directly following interaction with the physically interactive model, students in the intervention group did experience a shift in their source of motivation. Instead of a majority of students reporting that their primary goal regarding the course was to "Get an 'A'"- such as was seen in the preliminary survey - the majority of primary goals regarding the course after interaction was equally distributed amongst "Get an 'A'" and "Learn the material". This shift indicates that interaction with the model did influence at least some students' towards intrinsic motivation.

- *Attitudes and Motivations for Education – Checkpoint Surveys*

For all three groups, the majority of students chose either "Get an 'A'" or "Learn the material" as their primary goal in the course throughout the first semester. All groups, however, experienced varying shifts between being extrinsically motivated by grades and intrinsically motivated by the will to learn the material.

Results from the first checkpoint survey indicate that the majority of students in all three groups were extrinsically motivated by grades after the first exam. This was also true following the second exam, however there were more students in each group shifting towards intrinsic motivation. By the third checkpoint survey, both the control group and the activity control group saw huge increases in the number of students who were intrinsically motivated by the will to learn the material. For both of these groups, results from the third checkpoint survey indicated that the majority of students were intrinsically motivated. For the intervention group, however, the number of students who shifted towards intrinsic motivation only rose enough to match the number of students with extrinsic motivations based on grades.

Results from the checkpoint surveys reveal that students in all three groups shifted their motivations throughout the course. These shifts, however, seemed more drastic for the control group and the activity control group, whereas the shifts for the intervention group were more gradual.

- Attitudes and Motivations for Education – End of Course (Final) Survey

Just before the final exam, the control group saw a drop in the number of intrinsically motivated students so that it now matched the number of students extrinsically motivated by grades. The activity control group saw a large drop in the number of intrinsically motivated students at the same time as a spike in the number of students extrinsically motivated by grades so that the extrinsically motivated students again made up the majority of the group. In contrast, the number of intrinsically motivated students in the intervention group steadily rose while the number of students extrinsically motivated by grades steadily decreased so that, for the first time in the duration of the study, the intervention group was composed of a majority of intrinsically motivated students.

Results from the end of course survey reveal that more students in both the control and the activity control groups were extrinsically motivated as the final exam approached. However, the number of intrinsically motivated students in the intervention group rose as the final exam approached.

- *To determine whether any change in students' source of motivation after engaging with a physically interactive model is retained throughout the remainder of the students' undergraduate career.*

While the positive change in students' source of motivation after engaging with a physically interactive model was not consistently maintained throughout the first semester of the study, it did have an impact on the rate of change in the source of motivation throughout the first semester.

- Attitudes and Motivations for Education – Future Course Survey

At the conclusion of the physiology or histology courses, all groups were composed of a large majority of students who were intrinsically motivated due to a large spike in the number of these students and a large drop in the number of students extrinsically motivated by grades.

Results from the future course survey reveal that large numbers of students in all groups made the shift from being extrinsically motivated by grades, to being intrinsically motivated by the will to learn. This shift was, however, largest for the activity control group, followed by the control group. The shift in the number of students for the intervention group was more gradual as the majority of students in this group were already intrinsically motivated after the first semester of the study.

6.2 Hypothesis #2: Study Habits

"Engaging with a physically interactive model will have a positive and sustained influence on students' study habits."

6.2.1 Research Outcome

- *To determine the extent to which supplemental instruction with a physically interactive model will affect study habits adopted by students studying for the life sciences.*
    - *To determine whether this effect is positive or negative.*

      The effect of supplemental instruction with a physically interactive model seemed to negatively (moved them towards memorization) impact study habits adopted by students studying for the life sciences.

        - *Attitudes and Motivations for Education – Preliminary Survey*

          Considering both mean and mode results from the preliminary survey, it appears that students in the control group and the intervention group came into the Biomedical Anatomy course prepared with a study plan different than that which they employed in previous courses. The activity control group, however, seemed unsure about their study plan for the Biomedical Science course compared to their plans for previous courses.

The control and intervention groups also saw relatively more value in the courses that challenged them and realized that practicing application of information was more valuable for learning. However, all three groups did not believe that they learned more from memorization than from practicing application and were unsure (considering both mean and mode responses) about their general enjoyment of studying, being challenged in courses, and whether they preferred to memorize when preparing for a test rather than practice application.

Results from the preliminary survey indicate that students in all groups began the first semester of the study without a preference for memorization. However, students in the control and intervention groups did plan to approach the Biomedical Anatomy course with a study plan different than what they had used in the past.

- *Attitudes and Motivations for Education – Checkpoint Surveys*

Considering both mean and mode results from the first checkpoint survey, students in all groups seemed to be unsure about whether their study method for the first exam differed from previous exams. Students in all groups did, however, agree that they planned on making significant changes in their study methods for the second exam.

The same results from the second checkpoint survey indicated that the activity control group, as well as the intervention group, both made significant changes in their study methods after the first exam. Students in all groups also indicated that they were content with the change and did not plan to change their methods again in preparation for the third exam.

The third checkpoint survey revealed that students stuck with their study methods from the second exam when preparing for the third exam. Although slightly more unsure for all groups, students also indicated that they would not be making a significant change to their study methods for the final exam.

Specifically, the control group indicated that their study method for the first exam was significantly different from previous exams, but that they also planned to change their study methods after taking the first exam. For the second and third exam, students in the control group reported that they did not actually change their study methods and now did not plan on changing.

Students in the activity control group indicated that their study methods for both the first exam and the second exam were significantly different than previous exams. However, they did indicate that they planned to change their study methods significantly more after the first exam than after the second and third.

Students in the intervention group followed a similar trend as they indicated that their study method for the first exam was significantly different than previous exams as well as the second and third exam. These students also indicated that they planned to significantly change their study methods after the first exam, but were more unsure about changing their methods after the second and third exams.

Checkpoint survey results indicate that, for all groups, students had revised their study methods before the first exam, but planned to continue revising them after the first exam. The activity control group did in fact continue to revise their study method for the second exam and were then content with their methods. The intervention group was more unsure about whether they continued to revise their study methods for the second, but indicated that they were content with their study methods from there on. Students in the control group indicated that they did not continue to revise their study methods as planned and were in fact content with the study methods they had originally started out with for the first exam.

- *Attitudes and Motivations for Education – End of Course (Final) Survey*

  The end of course survey results revealed that students in the control and activity control groups both enjoyed practicing application of information while studying for the Biomedical Anatomy course significantly more than students in the intervention group.

  In addition, where students in the activity control group had previously placed relatively more value on memorization than the other two groups at the beginning of the course, both the activity control and control groups placed a lower value on memorization by the end of the course compared to the intervention group.

  Students in the control group did, however place more value on memorization over application at the end of the course than they had at the beginning of the course, as did the intervention group.

Results from the end of course survey indicate that both the activity control group and the control group shifted toward using application of information more over the course of the semester whereas students in the intervention group actually saw more value in memorization at the end of the semester.

- *To determine whether any change in students' study habits after engaging with the physically interactive model is retained throughout the remainder of the students' undergraduate career.*

The negative effect (move toward memorization) seemingly influenced by engaging with the physically interactive model was retained throughout the remainder of the students' undergraduate career.

- *Attitudes and Motivations for Education – Future Course Survey*

Responses for the future course survey indicated that students in the intervention group relied significantly more on memorization when studying throughout the second semester of the study.

Both the activity control and control groups saw a significant decrease in how much they relied on memorization while studying during the second semester. The control group also experienced a drop in their enjoyment of studying whether using application of information or memorization.

6.3 Hypothesis #3: Academic Performance

"Engaging with a physically interactive model will have a positive and sustained influence on students' academic performance in life science courses. This influence will be greater and more positive for students with high to intermediate spatial ability."

6.3.1 Research Outcome

- *To determine the extent to which supplemental instruction with a physically interactive model will affect students' academic performance in life science courses."*
    - *To determine whether this effect is positive or negative.*

        Students who had supplemental instruction with a physically interactive model improved their academic performance for most assessments. However, in some instances, students in one or both control groups also improved. Therefore, whether the model had a positive effective is inconclusive.

        - *Quizzes*
            - *Thoracic Limb Myology and Basic Biomechanics:*

                Students in all three groups experienced a significant increase in their scores for these quizzes, however the improvement for the activity control group was significantly lower than both the control and intervention groups. In addition, although it was not significantly different from the control group, the intervention group did have the greatest improvement between quizzes.

                These results indicate that the physically interactive model and/or the in-lab activity may have had some impact on students' academic performance for this topic.

- *Skeletal Muscle Histology and Physiology:*

  The scores for this topic only increased in the control group, and the increase was not significant. The activity control group and the intervention group both experienced decreases in scores, but, again, the difference was not significant.

  These results indicate that the physically interactive model and/or the in-lab activity likely did not have an impact on students' academic performance for this topic.

- *The Peripheral Nervous System:*

  Both the control group and the intervention group experienced significant increases in their scores for these quizzes. In addition, although the difference was not significant, the intervention group had the greatest improvement between quizzes.

  These results indicate that the physically interactive model and/or the in-lab activity may have had some impact on students' academic performance for this topic.

- *Integration:*

  All three groups experienced significant increases in scores between quizzes for this topic. For this quiz, the activity control group improved significantly more than the other two groups.

  These results indicate that the in-lab activity may have had some impact on students' academic performance for this topic.

▪ *Course Exam Scores*

- *Laboratory Exams:*

  No significant difference was seen amongst groups for the first laboratory exam, however the control group did score significantly higher than the intervention group for the following three exams. The control group, however, scored significantly lower than the activity control group for the third exam, but significantly higher than the same group for the final exam.

  These results indicate that the physically interactive model may have had some impact on the students' academic performance overall, although more research is required for conclusive results.

- *Lecture Exams:*

  Lecture exam scores for the first and third exams did not differ significantly amongst groups. However, the intervention group did score significantly lower than both groups for the second exam. Both the activity control group and the intervention groups scored significantly lower than the control group on the final exam.

  These results indicate that the physically interactive model and/or the in-lab activity likely did not have an impact on students' academic performance overall.

o *To determine whether this effect is influenced by spatial abilities.*

The positive effect of supplemental instruction with a physically interactive model on students' academic performance may have been influenced by their spatial abilities. However, performance assessments in both control groups were also affected by spatial abilities.

- *Spatial Assessments*

The preliminary quiz for thoracic limb myology and basic biomechanics was positively correlated to four of the five spatial assessments. The post intervention quiz for the same topic was only positively correlated to one. However, the change in quiz scores for this topic was negatively correlated to three spatial assessments. This could indicate that students with higher spatial abilities grasped these concepts more quickly and were, therefore, less likely to improve from their first quiz score.

The preliminary quiz for skeletal muscle histology and physiology was positively correlated to two spatial assessments, whereas the post intervention quiz and change in quiz score for this topic were both only correlated to one – the change in quiz score being a negative correlation. This likely indicates that spatial abilities had little to no impact on students' performance on these assessments.

The preliminary quiz for the peripheral nervous system was positively correlated to three of the five spatial assessments, whereas the post intervention quiz and change in quiz score for this topic were both negatively correlated with two spatial assessments. This could indicate that students with higher spatial abilities may have grasped these concepts more quickly.

The preliminary quiz for integration of the topics was positively correlated to four of the five spatial assessments, however the change in score for quizzes involving integration of topics was negatively correlated to three spatial assessments. This could indicate that students with higher spatial abilities grasped these concepts more quickly and were, therefore, less likely to improve from their first quiz score.

The first laboratory exam was positively correlated to four spatial assessments and the third laboratory exam was positively correlated to two. All of the lecture exams, except for the third, were positively correlated to three out of the five spatial assessments. The third lecture exam was positively correlated to two spatial assessments. This could indicate that students with higher spatial abilities were more likely to perform well on the first laboratory exam as well as the first, second and final lecture exams.

Overall, the ASRA 3 seemed to have the most impact on performance assessments, affecting 21 assessment measures total for all groups, four negatively and 17 positively. The Crystal Slicing Test seemed to have the least impact on performance assessments, only affecting five assessments total for all groups, one of those effects being negative.

The intervention group's performance assessments seemed to be the most affected by spatial abilities as a total of 25 instances of a spatial assessment correlating to a performance assessment were identified. Seven of these correlations were negative. For the activity control group, total of 24 instances of a spatial assessment correlating to a performance assessment were identified, with only two of those correlations being negative. Finally, for the control group, a total of 22 instances of a spatial assessment correlating to a performance assessment were identified, with five of those correlations being negative.

It is important to note, however, that significant differences in spatial assessment scores were only found for two assessments amongst groups. This indicates that, while spatial abilities may have had an effect on performance assessments, the effect was likely not different amongst groups.

7 DISCUSSION

7.1 Motivations

Personal observations gathered from informal conversation with instructors indicate that students coming into the Biomedical Anatomy course are primarily extrinsically motivated. These observations are supported by studies in other life science courses (Anderton, Chiu & Aulfrey, 2016; Eleaser & Kelso, 2018). Similarly, this study also found that incoming students are primarily motivated by extrinsic factors such as grades (i.e. "Get an 'A'"). The nature of the Biomedical Anatomy course, however, both allows and encourages students to come up with unique conclusions using critical thinking. As a result, students' motivations began to shift towards more intrinsic factors such as a will to learn the material.

Both the activity control and control groups experienced dramatic shifts in motivations between the second and third exams. Although smaller, the intervention group experienced a similar shift. The content being presented at the time of these shifts may provide an explanation. Material in the Biomedical Anatomy course is presented so that the large majority of the musculoskeletal system is covered before the second exam. After the second exam, the material shifts towards body systems and organs, such as the cardiovascular system. Instructors have anecdotally noted a peak in students' interest at this point in the course. Investigating the intricate workings of essential organs may distract students from the competition for good grades. With the competition aside, students focus instead on the perceived value of the content.

The effect of the change in material being presented did not seem to be sustained past the third exam. Both the activity control and control groups experienced an increase in numbers of students reporting extrinsic motivations following the third exam. This could have less to do with a loss of interest in the material and more to do with approaching exams. The final exam in the

Biomedical Anatomy course is worth double the points of a regular course exam. For this reason, the final exam can often be a determining factor for students' final grade in the course. As this exam approaches, students likely lose sight of the value of the content and shift their focus again towards their grades.

For the intervention group specifically, there was a rise in the number of students reporting more intrinsic motivation immediately following interaction with the model. Students were asked to construct their own knowledge through experimentation and reflection by interacting with the physical model. This may have helped to spark a sense of autonomy and self-worth. In return, students likely felt better equipped to discover new material using critical thinking skills. As learning the material became less overwhelming, students were able to realize that "Getting an 'A'" would come naturally after shifting their focus to "Learning the material". Further, interaction with the model before the first exam allowed students in the intervention group to shift their motivations earlier in the semester as compared to the other two groups. This likely contributed to the relatively more gradual shifts in motivation that the intervention group experienced.

At the conclusion of the physiology or histology course, many more students in all three groups reported that their primary goal was to "Learn the material". There are three influences that may explain this result:

1. For most students, the second semester of the study was the last semester before graduation. By this time, students who applied to professional programs (most BIMS students) already knew whether they were accepted. Knowing that they only need to pass the course or maintain their grade point average relieves students of the pressure to make an "A". This allows students to shift their focus once again to learning the material.

2. The difficulty of the physiology course (which most Future Course Surveys were collected from), may also provide an explanation. The Biomedical Physiology course is well known for the challenge it presents to students and not many are able to make an “A” in the course. Students likely chose “Learn the material” as their primary goal simply because “Get an ‘A’” was no longer attainable.
3. Physiology presents new and more abstract concepts to students who have just finished the anatomy course. Some students may have found the material in the physiology course better suited to their interests and abilities.

7.2 Study Habits

Both the intervention and control groups reported that their study plan for the Biomedical Anatomy course was different than that for past life science courses. This could be explained by the anticipated nature of information presented in the course. Instructors have anecdotally noted that incoming students feel the appropriate approach to the Biomedical Anatomy course is to memorize OAIs (Origins, Insertions and Actions) for muscles.

The ability of students to adapt and change their study methods as the course proceeds is reflected in their test scores. The intervention group reported changing their study methods after the first exam, but also reported finding more value in memorization throughout the semester. This reliance on memorization could be a contributing factor to their consistently lower exam scores. Many possible reasons why these students chose to rely on memorization were explored:

1. Because this shift towards memorization as a study method is only seen in the intervention group, it could be attributed to the use of the physically interactive model. The basic tenants in constructivism, ELT and CLT support the design and use of the model. However, some ideas within the ZPD model provide an explanation for the relationship

between change in study method and using the model. Scaffolding tools should provide just enough support for students to accomplish a task (such as learning a complex concept) (Berk and Winsler, 1995; Darling-Hammond and Bransford, 2005; Murphy, Scantlebury and Milne, 2015; Vygotsky, 1977). However, if the scaffolding is overly sufficient, it can end up robbing the learners of some of the complex interactions that support cognitive development, essentially "doing it for them" (Murphy, Scantlebury and Milne, 2015). This explanation, however, would only hold true through the first exam as the physically interactive model was only used for those lessons. The consistently lower performance of the students in the intervention group throughout the semester, however, suggest that the model had little to no impact on the sustained reliance these students had on memorization.

2. Both the Biomedical Anatomy and the Biomedical Physiology course are firmly based in application of information. In addition, one section of the control group completed the courses concurrently with the intervention group. For these reasons, the content and presentation of information is not likely to have caused students in the intervention group to rely more heavily on memorization.
3. Some instructors across the life sciences have anecdotally noticed a change in students as the newer generation begin to make up the majority of classes. Students seem to be more entitled, less appreciative and consistently opposed to hard work. As a result, students expect to put in less effort and be given more resources. In addition, students are more likely to perceive low scores as a personal affront rather than a reflection of their efforts or understanding. These observations, and their consequences, are supported by research in higher education and educational psychology (Altman, Prittie and Forbach, 2019;

Anderson, Halberstadt and Aitken, 2013). However, students in the control group who took the Biomedical Anatomy course concurrently with the intervention group did not have the same results in regard to study methods. For this reason, a progressive attitude change in the population of students does not explain the intervention group's reliance on memorization.

7.3 Academic Performance

The puzzling insistence on memorization within the intervention group and other factors contributing to their consistently lower scores which are unrelated to the intervention model make determining the impact of the model challenging.

Students in the control group scored consistently higher on exams, whereas students in the intervention group scored consistently lower. However, both groups had significantly more improvement between quizzes for the topics involving biomechanics as well as the peripheral nervous system as compared to the activity control group. In addition, the intervention group had the higher improvement in scores for both topics. The ability of students in the intervention group to achieve scores comparable to the higher-performing control group for these topics may indicate a positive impact caused by the intervention. However, further research on the implementation of the model is needed to determine the impact of the model conclusively.

7.3.1 The Influence of Spatial Abilities

In general, results indicate that students with higher spatial abilities perform better on assessments in the anatomy course. Specifically, skills in the combined areas of spatial orientation and penetrative thinking, as were measured by the ASRA, seem to be the most influential on student performance (Lohman, 1979; Ormand, 2017).

Only two of the five spatial assessments showed a significant difference in spatial abilities amongst groups. This indicates that all three groups had similar spatial abilities overall. However, scores for the intervention group on the third ASRA were significantly lower than scores for both the control and activity control groups. In addition, the third ASRA was the spatial assessment with the most influence on performance assessments. This may suggest that the specific abilities of students in the intervention group to spatially orient themselves while using penetrative thinking could have impacted the effects of interacting with the model.

7.4 Qualitative Feedback on Model Interaction

Students in the intervention group had overwhelmingly positive feedback regarding their interaction with the model. This indicates that there was some perceived benefit in using the model across multiple subject matters. Qualitative results also imply that the students enjoyed interacting with the model and working with their groups. This could indicate that students in the intervention group were more engaged during laboratory and lecture sessions. These results should be considered when revising the model and designing further studies.

7.5 Pitfalls and Limitations

As this study included many students and many points of analysis, were a considerable number of pitfalls and limitations that should be noted.

The first of these includes some possible sample biases due to the starting time for different laboratory sections of the course. Students self-selected which laboratory section they were enrolled in based on the meeting times offered. This self-selection could mean that students who selected to be in earlier sections may have had pre-established attitudes and study habits, different from students who selected the later sections. To account for the variable of starting time, all three study groups (control, activity control and intervention) each included students from at least one section with a starting time of 8am and students from at least one section with a starting time of 9 am or later (see Table 9). In this way, each of the groups was assured to have students from sections with varied starting times.

A second possible pitfall is closely related to the first. Due to the limited number of sections offered, the activity control group was only run during the Spring semester while the control and intervention groups were only run during Fall semesters. This may have created some sample bias as students who took the Biomedical Anatomy course in the Spring may have had different pre-established attitudes and study habits than students who took the course in the Fall due to their success in previous courses or expected year of graduation. The presence or absence of this sample bias, however, was not evident when comparing expected year of graduation.

Another pitfall could be related to the issue of perceived success or failure on exams and the ability of that perception to influence survey responses. For this reason, in all but one unavoidable instance within the control group, checkpoint surveys were administered to students after they have received their grade for the preceding exam. This insured that students had a realistic view of how they were performing in the course before reflecting on their attitudes, motivations and study habits.

A major limitation for this study includes the consistency of student participation throughout the semester. With so many assessments at multiple points throughout the semester, many students did miss one or more of the assessments. However, the volume of students who completed a majority of the assessments was sufficient to account for this limitation in all but one circumstance. This circumstance was that of the Future Course Surveys collected for the control and intervention groups. Because the format and circumstances surrounding how this survey was administered, all purposed conclusions based heavily on the results from this data were either supported by other, more consistent, assessments, or were not included.

As expected, the model itself was a bit problematic. Regardless of the durability of materials or testing done on the model used for the intervention group, it was anticipated that some portion of the model would break or be damaged during interaction. To avoid issues in consistency of interaction with the model, multiple replacement parts were printed and stayed with the model. When issues arose during the intervention, the creator of the model, who is also an instructor in the course, was able to quickly and easily provide repairs or replacements or make adjustments to the activity so that students could continue to interact with the model.

Finally, perhaps one of the most influential pitfalls of this study was the time allotted for interaction with the physical model. Portions of the model that were axillary and could be made available to more than one group at a time did not present any issues in regard to time. However, as there was only one large model, making sure 24 groups of students each had at least five minutes to interact with the model and complete the activity within the two-hour lab period was difficult to say the least. Although there were timers set and students used every minute from the beginning to the end of the lab period, the five-minute time limit did not factor in time for students to ask many questions or repeat experiments with the model. This issue may have had a tremendous impact on the efficiency of the model as it was used to scaffold learning. For this reason, future research with the model should include either less students in a laboratory period, or more large models.

8 SUMMARY OF FUTURE RESEARCH

The possibility for future research with this model is incredibly vast has the potential to address multiple areas within life sciences educational practices. Primarily, a second study with this model should be implemented which allows students more time to interact with the model. This additional time could be the key to providing students the optimallevels of experimentation and reflection that will enhance their learning. There are many possible approaches to this future study including limiting the number of students in a laboratory section and building multiple models.

The impact of spatial abilities should also be further explored. For this study, the overall effect of spatial abilities was assessed for performance assessments, however, these abilities can be broken down into many levels and tested for correlations to multiple different variables within the study. For example, students with less skill in penetrative thinking may have a greater improvement in quiz scores for the peripheral nervous system after interacting with the model, but their performance in regard to concepts within the topic of biomechanics may be wholly unaffected. In addition, students' attitudes and study methods are likely affected by their spatial abilities based on the correlations found between their quiz scores and the spatial assessments.

Analyzing the effect of the physically interactive model by topic seemed to indicate that the model helped different students in different ways. Further breaking these topics down into concepts and objectives by analyzing each of the quizzes by question could reveal even more about the effect of the model for different students and different concepts. In addition, isolating those questions on the second, third and final exam that specifically pertain to the topics covered with the model could reveal more about how the model affects retention of the material learned.

For this study, the activity group was strictly included to eliminate the variable of the effect of guided study. However, many of the results indicated large differences when the activity control group was compared to the other two groups. Future research into the differences based on using a simple activity versus an interactive model could not only improve the implementation of interactive models in life science classrooms, but could also inform activity design and, therefore, help instructors to better scaffold their students' learning across different instructional formats.

Instructors have noticed that a students' perception of and performance within the Biomedical Anatomy course are greatly influenced by their dissection group members. As was hinted in some of the qualitative results pertaining to perceptions toward working in groups, a students' interaction within their group could be highly impactful in regard to their interaction with the physical model as well as other instructional tools. Group activities and laboratory quizzes are common assessment tools used in the Biomedical Anatomy course. Investigating the attitudes, approaches and performance of students as a group and/or within their group could help to inform the design of future models and other instructional tools.

Engagement surveys and informal interviews assessing students' level of participation and status of understanding for this study only served to standardized the interaction of instructors with students. However, this information could be analyzed to evaluate the progress of a student or group's study and their level of engagement and critical thinking. These variables could be influenced by interaction with the physical model or, conversely, these factors combined with the timing of interaction, could impact the extent and nature of the effect interaction with the physical model has on student learning.

Following each preliminary and post topic quiz, students were asked to determine a "Muddiest Point" or a concept that was most unclear for them at that moment. For this study, the Muddiest Point was only used as a point of reflection for the students benefit. However, a thematic analysis of the Muddiest Points could inform results related to the attitudes, approaches and performance of students throughout the course. This analysis could also help to inform future development of the physical model and the concepts which it illustrates.

Finally, as was discussed for this study, students' first interactions and scores within the Biomedical Anatomy course may be influenced by their preconceived perceptions, expectations and attitudes regarding the course and learning in general. A study which implemented a similar model during the second unit of the course, that is, between the first and second exams, may reveal drastically different results. Observed results from this study indicate that students generally earned the lowest scores on the first exam in the course regardless of the group they were in (control, activity control, or intervention). Most then altered their study habits, and began earning higher scores on subsequent exams. Asking students to use a physically interactive model for studying when their previously established and trusted study methods are already being challenged at the beginning of the course, may have had some influence on the students' attitudes towards the model and its impact on their learning. If students were allowed the time at the beginning of the course to become accustomed to the format of the course and get a better understanding of what will be asked of them throughout the semester, they may be more willing and better equipped to use their interactions with the physical model to inform their understanding, attitudes and approaches towards learning.

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APPENDIX A

IN-LAB ACTIVITIES

Model Activities

BIOMECHANICS

Print your names and table number on the BACK of the second page
DO NOT list the names of group members who are not present

For this activity, you will be interacting with the physical model.

Everyone in your group should help to complete the activity.

Today you will be interacting with the canine and human thoracic limbs on the model. Each string on this model represents a muscle. Pulling on a string represents the respective muscle's contraction. Muscles belonging to the same group are all the same color.

ON EITHER THE HUMAN OR THE DOG MODEL:
Answer this question first: The skeletal models of the human and canine thoracic limb have some areas painted blue (labeled "A") and some areas painted red (labeled "B"). Which of these areas represents the flexor surface of the joints? *(Circle one)*

Blue (A) Red (B)

1. Find the two eyehooks on the skeleton and the shoelace provided. Loosely tie the shoelace to the red eyehook and run it through the blue eyehook. Now pull the shoelace. Which eyehook is the most moveable (i.e. which one moves)?

   ____

   This indicates that, if this were an actual muscle, its insertion would be represented by which eyehook? (circle one)

   Red Blue

2. Each of the following questions pertain to the ***yellow*** string labeled "***#1***".

   a. Does this muscle cross the ***flexor surface*** of any of these joints? *(circle either yes or no for each of the following joints)*

      i. Shoulder? Yes No

      ii. Elbow? Yes No

      iii. Wrist/Carpal? Yes No

b. Does this muscle cross the ***flexor angle*** of any of these joints?
(circle either yes or no for each of the following joints)

i. Shoulder? Yes No

ii. Elbow? Yes No

iii. Wrist/Carpal? Yes No

ON THE DOG MODEL:

c. What is the ***action(s) of this muscle*** & ***which muscle group does it belong to***? (hint – pull the string!)

____

____

d. Have one person in your group hold any other strings that cross the same *flexor angle(s)* (joint(s)) as this muscle. Now have someone else pull on the string labeled "#1".

i. Which string(s) have to be let go in order for the #1 string to create movement? *(Identify strings by color)*

____

ii. In this scenario, the string being pulled is acting as a(n) ____________________, while the string(s) that have to be let go are acting as ___________________.

e. Suppose the muscle represented by string "#1" is acting as an agonist. Which string could you pull to act as a synergist to muscle #1? *(There may be more than one answer, you only have to list one; identify strings and color)*

____

3. Fill in each blank space with either **flexes, extends, is/are fixed, is/are unaffected.**

Find the string labeled "#2A" and the string labeled "#2B". Pull both strings with approximately equal force. When you do this, the carpal joint ____________________, the proximal interphalangeal joints _________________ and the distal interphalangeal joints _____________________.

<u>ON THE MODELS LOCATED IN THE BACK OF THE LARGE LAB</u>

4. For this portion of the activity, you will need to refer to one disarticulated scapula, one disarticulated ulna and one disarticulated humerus which are located near the model.
   a. How would you describe the attachment of the felt to the scapula? *(Circle One)*

      Aponeurotic　　　　Fleshy　　　　Tendinous

      i. The felt represents the **<u>origin / insertion</u>** *(circle one)* of what muscle *(list below)*?

         ____

   b. How would you describe the attachment of the fabric to the humerus? *(Circle One)*

      Aponeurotic　　　　Fleshy　　　　Tendinous

      i. The fabric represents the **<u>origin / insertion</u>** *(circle one)* of what muscle *(list below)*?

         ____

   c. How would you describe the attachment of the elastic to the ulna? *(Circle One)*

      Aponeurotic　　　　Fleshy　　　　Tendinous

      i. The elastic represents the **<u>origin / insertion</u>** *(circle one)* of what muscle *(list below)*?

         ____

SKELETAL MUSCLE HISTOLOGY & PHYSIOLOGY

Print your names and table number on the BACK of the second page
DO NOT list the names of group members who are not present

PART #1

For this portion of the activity, you will be interacting with the histological model of a muscle on the model as well as with the sarcomere model.

Everyone in your group should help to complete the activity.

1. Using the letters on the model, place the letter that corresponds to each structure in the correct blank. Each one only has one answer.

__________	Endomysium	__________	Muscle
__________	Epimysium	__________	Neurovascular Bundle
__________	Fascicle	__________	Perimysium

   List one structure that could be negatively affected if the structure represented by letter **"A"** is disrupted?

   ____

2. The different components of the sarcomere are labeled with letters ***A-F***. As you work through the instructions, identify the component of the sarcomere being represented based on its appearance and function in the box to the right.

   Step #1: Place the component labeled "***E***" inside of the component labeled "***A***". They should stick together with a magnet.
   Step #2: Gently push the complex you just created with "***E***" and "***A***" so that "***F***" is no longer covering "***C***".
   Step #3: Rotate the structures labeled "***B***" so that they are near a "***C***" by pressing the *blue* button.
   Step #4: Once the "***B***" and "***C***" components are close, continue to rotate the ***"B"*** structures with the *blue* button while gently pressing the two "**D**" components together.
   Step #5: Replace all components back to the way they were when you first came up to the model. Rotate the ***"B"*** components back by pressing the *yellow* button.

   Identify Components Here

   A. _______________
   B. _______________
   C. _______________
   D. _______________
   E. _______________
   F. _______________

   Which component could be found in any area of the A band at any point during contraction? *(Choose a letter/letters from the list above)*

   ____

   Which would be found in the I band? *(Choose a letter/letters from the list above)*

PART #2

For this portion of the activity, you will be using one of the "Muscle Building" kits provided by an instructor.

Everyone in your group should help to complete the activity.

For this portion of the activity, half of your lab group will be building a muscle with fine (precise) control. The other half of your lab group will be building a muscle with coarse control. Make sure to coordinate amongst yourselves as each muscle's level of control will be relative to the other's.

Supplies:

- **Muscle Fibers:** *(Note: The color of the dowels you use does not matter for this activity)*
  - **8 contracted (shorter dowels)**
  - **15 relaxed (longer dowels)**
- **Connective Tissue Layers:** *(Make sure to include each of these layers in the correct locations! You do not have to cover the entire structure – this is only a representation.)*
  - **Endomysium (plastic wrap)**
  - **Perimysium (foil)**
  - **Epimysium (PlayDough)**
- **Axons of Motor Neurons (Yarn)**
  - Use yarn to represent axons, pull the ends of the yarn apart to create axon terminals.
- **Neuromuscular Junction (Tape)**
  - Use the tape to connect each axon terminal to a muscle fiber.

Muscles:

- **Muscle #1:**
  - This muscle should represent a muscle with fine (precise) control
  - This muscle should be 50% contracted. *(Keep in mind that all cells belonging to a single motor unit will contract together)*
- **Muscle #2:**
  - This muscle should represent a muscle with coarse control
  - This muscle should be 25% contracted. *(Keep in mind that all cells belonging to a single motor unit will contract together)*

Once you believe that you have each of these muscles built correctly, (there are many ways to complete this activity correctly), have an instructor check your work and sign off below. Then you can continue to answer the questions.

Muscle #1: Precise control, 50% contracted, **Instructor Initials: ____________**	***Muscle #2:*** Coarse control, 25% contracted, **Instructor Initials: ____________**

3. Place the number of the muscle (from the muscles you just built) that would be most appropriate to use for each of the following activities according to the ***amount of control* and *force required***.

   ______ Kicking a Soccer Ball Across the Field

   ______ Moving the Eyeball Side-to-Side

4. The following is a *hypothetical situation based on the motor units given to you in your kit (blue, orange, and green yarn attached to dowels)*:
   a. First determine the size of each motor unit and what that means about the amount of control and force it has.
   b. You are attempting to lift a 10lb weight exactly 5 inches off a table.
      ii. First you recruit 3 blue motor units, 1 orange motor unit, and 5 green motor units.
         1. You were able to lift the weight off the table, but you were unable to control the movement enough to stop at exactly 5 inches.
      iii. Propose a combination of motor units that would allow you to lift the weight with enough control. *(There is more than one correct answer, you are not limited in the amount of motor units you use.)*

Number of Blue Motor Units: ____________

Number of Orange Motor Units: ____________

Number of Green Motor Units: ____________

<u>The Peripheral Nervous System</u>

<u>Print your names and table number on the BACK of this page</u>
<u>DO NOT list the names of group members who are not present</u>

For this activity, you will be interacting with the physical model.

<u>Everyone</u> in your group should help to complete the activity.

Today you will be interacting with the nervous system components of the model, which includes everything but the skeletal models and the sarcomere model. The LED strips on this model represent cellular processes (axons/dendrites) of neurons. Neurons will light up when activated and the information will be transmitted to its destination (represented by lights moving across the LED strips).

<u>Part 1</u>

*********<u>ANSWER #1A, #2A, #3 & #4 BEFORE ANSWERING #1B-D & #2B-D</u>**********

1. Press on the skin over the humerus mounted on the back board of the model.
   a. Which direction does the impulse travel? *(Circle One)*

      CNS -> PNS   CNS <- PNS

   b. Based on the direction of impulse, what term could you use to describe any of these neurons?

      ____

   c. How would you classify the function of these neurons? *(Circle One)*

      Sensory   Special Sensory   Motor

   d. Now that you know the direction of impulse and function of the neurons, how would you classify the neurons according to the number of cellular processes?

      ____

2. Now press any red button on a spinal cord segment.
   a. Which direction does the impulse travel? *(Circle One)*

      CNS -> PNS   CNS <- PNS

   b. Based on the direction of impulse, what term could you use to describe this neuron?

      ____

c. How would you classify the function of this neuron? *(Circle One)*

Sensory Special Sensory Motor

d. Now that you know the direction of impulse and function of the neuron, how would you classify this neuron according to the number of cellular processes?

____

3. Describe how the axon for the middle motor neuron is different in appearance from the axon of the bottom motor neuron.

____

____

4. Press the red button for the middle motor neuron, then press the red button on bottom. Which neuron's impulse reached its destination quicker? Why do you think this happened?

____

PART 2

Use the labeled spinal cord segments located at the back of the large lab to answer the following questions. <u>You can complete Part 2 without having completed Part 1!</u>

5. Identify, by the letter on the model, where a cell body of the neuron type in ***question #1*** could be located. (*i.e. not the letter on the cell body itself, but the letter on the location where these cell bodies would be found).*

____

6. Identify, by the letter on the model, where a cell body of the neuron type in ***question #2*** could be located. (*i.e. not the letter on the cell body itself, but the letter on the location where these cell bodies would be found).*

____

7. Using the letters on the spinal nerve models, place the letter that corresponds to each structure in the correct blank. For each structure also circle either "PNS" or "CNS" according to which anatomical division of the nervous system it can be found/is a part of. Each one only has one answer.

Letter from Model	Structure	Anatomical Division
	Body of a Pseudounipolar Neuron	CNS / PNS
	Body of a Multipolar Neuron	CNS / PNS
	Dorsal Root of a Spinal Nerve	CNS / PNS
	Dorsal Root Ganglion of a Spinal Nerve	CNS / PNS
	Ventral Root of a Spinal Nerve	CNS / PNS
	Dorsal Branch of a Spinal Nerve	CNS / PNS
	Ventral Branch of a Spinal Nerve	CNS / PNS
	Grey Matter of the Spinal Cord	CNS / PNS
	White Matter of the Spinal Cord	CNS / PNS

a. In which area(s) listed above would you find at least one portion of both a multipolar and a pseudounipolar neurons? *(Choose **letters** from the list above)*

____

Integration

Print your names and table number on the BACK of the second page
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Use the following case vignette and the interactive models to determine the answers to the questions:

READ THIS CASE VIGNETTE BEFORE BEING CALLED INTO THE SMALL LAB TO COMPLETE THE ACTIVITY

A 28-year-old woman is admitted to the hospital after experiencing muscle pain and weakness. The patient reveals that she had been trying to recover from a Zika infection. You suspect Guillain-Barre Syndrome, an autoimmune condition associated with these types of infections that destroys Schwann cells by inflammation and demyelination of peripheral nerves and motor fibers.

You conduct an electromyography (electrodes inserted into the muscle to measure nerve activity) and nerve conduction studies (electrodes on the skin above nerves that send a small shock through the nerve to measure the speed of the nerve).

Results from these tests are not consistent with Guillain-Barre Syndrome.

You return to the woman's room to give her the results of her tests when she informs you that she has been experiencing strong spasms in her extremities.

You do a quick physical exam and discover that the woman's muscle tone and reflexes are extremely heightened (sensitive / overactive).

To give the woman some comfort while you try to figure out what is going on you prescribe tubocurarine, a nondepolarizing drug which is a competitive antagonist for (competes with) Acetylcholine.

You review the electromyography and nerve conduction study results and perform new ones on the upper extremity only.

These tests, along with a few others, lead you to diagnose an upper motor neuron lesion in the lateral corticospinal tract. This area of the spinal cord is involved in voluntary motor control of the upper extremities. (Upper motor neurons are the neurons which descend from the brain to tell the motor neurons associated with spinal nerves – lower motor neurons – to send impulses to skeletal muscles.)

PART 1:

1. ***Circle one region and the letter*** in that region which corresponds to the most likely place to find remnants of destroyed Schwann cells. *(There is only one answer – circle **one** region and **one** letter from that region)*

   Regions:

Spinal Nerve Segments	**A**	**D**	**G**
Histology Model (Muscle Model)	**B**	**E**	**H**
Skeletal Models	**C**	**F**	**I**

2. Look at the different axons represented on the model. The axons associated with which spinal nerve segment (*top, middle, or bottom*) most likely represent those from a patient affected by Guillain-Barre Syndrome? (*circle one*)

   Top ***Middle*** ***Bottom***

3. Press each red button, one at a time, and note the speed at which signals are transmitted to the muscle. Signals associated with which spinal nerve segment (*top, middle, or bottom*) are the slowest? The fastest?

   Slowest: ***Top*** ***Middle*** ***Bottom***

   Fastest: ***Top*** ***Middle*** ***Bottom***

4. Which of the spinal nerve segments (*top, middle, or bottom*) is the most likely representation of this patient's electromyography results? (*which would 100% rule out Guillain-Barre Syndrome*)

   Top ***Middle*** ***Bottom***

<u>Refer to the skeletal models for questions 5 & 6:</u>

5. Which color strings represent posterior antebrachial muscles?

   ____

6. Pull on one of these strings, what is the resulting action at the *wrist*?

   ____

7. Suppose you want to perform an electromyography to evaluate the spinal nerves associated with the brachial plexus. In order to do this, you place an electrode in the muscles represented by *blue string* on the skeletal models. In order to evaluate the *primary action* of these muscles while they are acting as *agonists*, what action should you ask the patient to perform?

   a. Flex the elbow
   b. Extend the elbow
   c. Flex the shoulder
   d. Extend the wrist
   e. Extend the shoulder
   f. Flex the wrist

8. In order to test the patient's reflexes, you apply sensory stimulation to the tendon of a muscle represented *in yellow*. Which action can you *definitely expect* to occur if the patient's reflexes are intact?

   a. Extend her elbow joint
   b. Flex her shoulder joint
   c. Extend her shoulder joint
   d. Flex her elbow joint

9. *For the purposes of this question we will assume that the muscle model represents a posterior antebrachial muscle.*

   a. Press the yellow button associated with the *dorsal-most* upper motor neuron. What signal is being transmitted to the muscle? (*circle one*)

   Nothing/No Signal ***Contract*** ***Relax***

   b. Press the yellow button associated with the *ventral–most* upper motor neuron. What signal is being transmitted to the muscle (*circle one*)?

   Nothing/No Signal ***Contract*** ***Relax***

   c. Now press the red button associated with the first (*top*) spinal nerve segment. What signal is being transmitted to the muscle (*circle one*)?

   Nothing/No Signal ***Contract*** ***Relax***

10. Consider all three of the buttons you just pressed –
    - ***a.*** the yellow button for the dorsal-most upper motor neuron (a)
    - ***b.*** the yellow button for the ventral-most upper motor neuron(b)
    - ***c.*** the red button for the first spinal cord segment (c)

Match the letter of the button (*a, b, or c*) with the appropriate clinical observation:

_____________ ***Normal movement after stimulating muscle/spinal nerve directly***

_____________ ***Inability to initiate voluntary movement***

_____________ ***Able to initiate voluntary movement***

11. ***Circle the clinical symptoms above*** that a patient with an upper motor neuron disorder will most likely demonstrate. (*There may be more than one*.)

12. Which division of the nervous system do the neurons associated with buttons *a* and *b* definitely belong to? (*circle one*)

Central ***Visceral*** ***Somatic*** ***Peripheral***

PART 2:

Please move to the Sarcomere Model for Part 2:

13. ***BEFORE DOING THIS PLEASE MAKE SURE YOU ARE PREPARED TO CATCH ANYTHING THAT MIGHT BE RELEASED FROM THE BOX***
Press the *green ACh molecule* into the *light blue receptor* on the box next to the sarcomere. What is released?

____

****** Please replace everything that came out of the box after answering the previous question******

14. What kind of clinical symptoms might someone see if what was inside of the box was not replaced each time it was released? (*circle all that apply*)
    - ***a. Muscle Weakness***
    - ***b. Muscle Stiffness***
    - ***c. Numbness***
    - ***d. Pain***

15. ***BEFORE DOING THIS PLEASE MAKE SURE YOU ARE PREPARED TO CATCH ANYTHING THAT MIGHT BE RELEASED FROM THE BOX***
Now put the *Tubocurarine molecule (purple and marked with a "T")* into the *light blue receptor* on the box.

a. Are you able to release any of the molecules? (*circle one*)

Yes ***No***

b. What is the *first step* in the contraction of skeletal muscle that the tubocurarine is preventing? (*circle one*)

a. Binding of ACh to receptors
b. Depolarization
c. Ca Binding to Troponin C
d. Myosin heads binding to active sites

c. What can a patient taking tubocurarine expect to experience while on the drug? (*circle one*)

a. Muscle spasms
b. Decrease in inflammation
c. Numbness
d. Muscle weakness

PART 3:

Complete part 3 with the spinal cord segments on the tables in the back of the lab. **You do not have to complete parts 1 and 2 in order to complete part 3.**

16. Identify, *by letter*, which component of a spinal nerve must be affected to cause muscle stiffness and spasms *in the upper limb only*?

____

17. What would you need to do to the component of the spinal cord you identified in the previous question in order to cause muscle stiffness and spasms? (*circle one*)

Provide prolonged stimulation ***Sever/Cut***

18. Which neuron type(s) are involved in a muscle reflex? (*circle all that apply*)

Multipolar ***Pseudounipolar*** ***Bipolar***

Control Activities

BIOMECHANICS

Print your names and table number on the BACK of the second page
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5. Each of the following questions pertain to the ***brachialis muscle***.
   a. This muscle crosses the flexor angle of which of the following joint(s)? *(circle the correct joint(s))*

      Shoulder   Elbow   Wrist/Carpal

   b. Does the muscle cross the flexor surface of any of these joints? *(circle either yes or no for each of the following joints)*

      i. Shoulder?

         Yes   No

      ii. Elbow?

         Yes   No

      iii. Wrist/Carpal?

         Yes   No

   c. What is the action(s) of this muscle & which muscle group does it belong to?

      ____
      ____

   d. The brachialis muscle is acting as an *agonist*. In order to act as an *antagonist* to the brachialis muscle, the ______________________ muscle *(you only need to list one muscle)* must __________________.

   e. The brachialis muscle is acting as an *agonist*. In order to act as a *synergist* to the brachialis muscle, the _______________________ muscle *(you only need to list one muscle)* must __________________.

6. *The paragraph below is about fictional muscles. Fill in each blank space with either* ***flex, extend, be fixed, be unaffected.***

Muscle A originates on the lateral epicondyle of the humerus and inserts on the palmar surface of the third and fourth metacarpals. Muscle B originates on the lateral epicondyle of the humerus and inserts on the dorsal aspect of the middle phalanges of all digits. If muscles A and B contract at the same time, the carpal joint will ___________________, the proximal interphalangeal joints will ________________ and the distal interphalangeal joints will ____________________.

7. Each of the following questions pertain to the ***supraspinatus muscle***.
    a. How would you classify the attachment on the scapula? *(circle one)*

        Fleshy   Aponeurotic   Tendinous

    b. How would you classify the attachment on the humerus? *(circle one)*

        Fleshy   Aponeurotic   Tendinous

    c. When this muscle contracts, which bone(s) is most likely to move?

        ____

_

    d. Based on your answers above, describe this muscles attachments by circling either ***fleshy, aponeurotic, or tendinous*** for each of the following:

        i. **Origin** – Fleshy   Aponeurotic   Tendinous

        ii. **Insertion** – Fleshy   Aponeurotic   Tendinous

8. Each of the following questions pertain to the ***lateral head of the triceps brachii muscle***.
    a. How would you classify the attachment on the bone(s) of the antebrachium? *(circle one)*

        Fleshy   Aponeurotic   Tendinous

b. How would you classify the attachment on the humerus? *(circle one)*

Fleshy　　　　Aponeurotic　　　　Tendinous

c. When this muscle contracts, which bone(s) is most likely to move?

____

_

d. Based on your answers above, describe this muscles attachments by circling either ***fleshy, aponeurotic, or tendinous*** for each of the following:

i. **Origin** – Fleshy　　Aponeurotic　　Tendinous

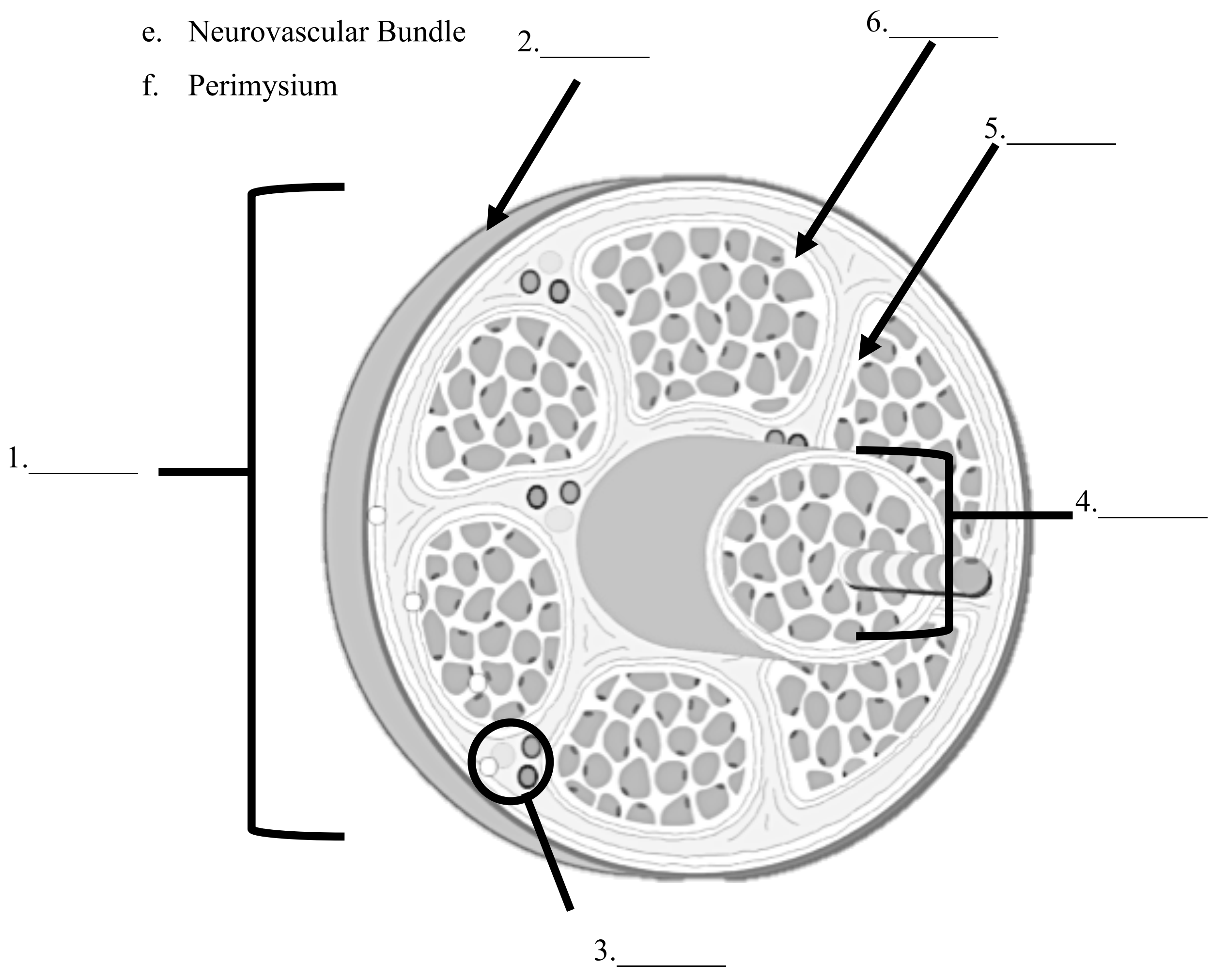
ii. **Insertion** – Fleshy　　Aponeurotic　　Tendinous

SKELETAL MUSCLE HISTOLOGY & PHYSIOLOGY

Print your names and table number on the BACK of the second page
DO NOT list the names of group members who are not present

1. The diagram below is a cross section of a muscle. Place the letter that corresponds to each structure in the correct blank. Each one only has one answer.

    a. Endomysium
    b. Epimysium
    c. Fascicle
    d. Muscle
    e. Neurovascular Bundle
    f. Perimysium



2. List one structure that could be negatively affected if the perimysium of any muscle is disrupted?

   ____

3. Rank the following activities from the one requiring the coarsest control (1) to the one requiring the most precise control (3):

   ______ Kicking a Soccer Ball Across the Field

   ______ Moving the Eyeball Side-to-Side

   ______ Lifting a 5-Pound Weight

   Now rank the activities from the one requiring the most force (1) to the one requiring the least (3):

   ______ Kicking a Soccer Ball Across the Field

   ______ Moving the Eyeball Side-to-Side

   ______ Lifting a 5-Pound Weight

4. The following is a *hypothetical situation*:
   a. There are three motor unit types:
      Motor Unit Type A = 1 axon to 10 muscle cells
      Motor Unit Type B = 1 axon to 50 muscle cells
      Motor Unit Type C = 1 axon to 100 muscle cells

   Muscle X recruits two *type A motor units* and three *type B motor units*. **Muscle Y** recruits two *type C motor units*. Which muscle's contraction will generate more force? *(circle one)*

   Muscle X **Muscle Y**

5. Number the following statements about muscle contraction in the correct sequence.

_______Myosin head binds to active site on actin

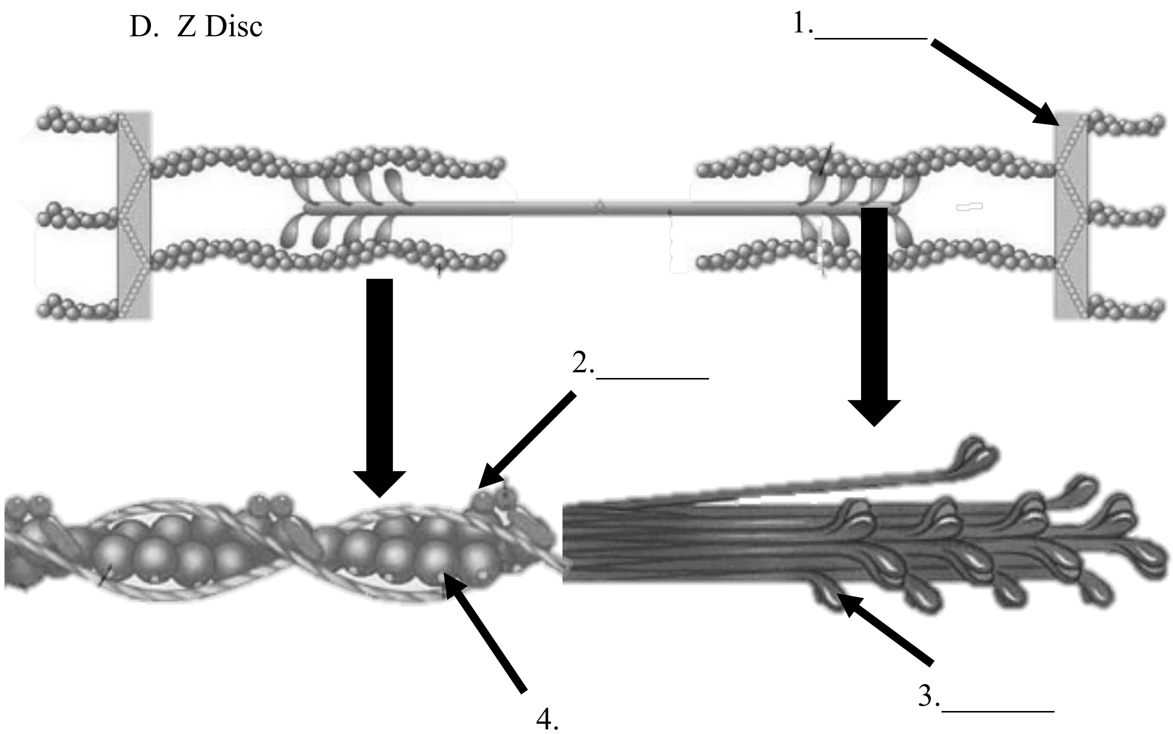
_______Calcium binds to troponin C

_______Myosin head pivots and pulls thin filaments toward center of sarcomere

_______Troponin lifts tropomyosin off active site

Label the following components on the diagram below:

A. Troponin C
B. Myosin (Head)
C. Active Site
D. Z Disc



Which component could be found in any area of the A band at any point during contraction? *(Choose a letter/letters from the list above)*

____

Which would be found in the I band? *(Choose a letter/letters from the list above)*

____

The Peripheral Nervous System

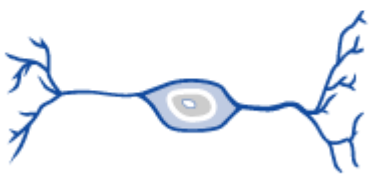
Print your names and table number on the BACK of this page

DO NOT list the names of group members who are not present

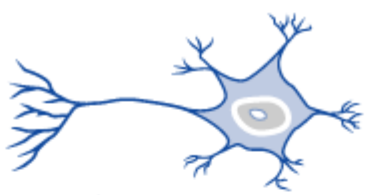
In the blanks next to each descriptor, list all of the cell types that it is describing.
The cell types are: **Pseudounipolar Neuron, Bipolar Neuron, Multipolar Neuron, and Schwann Cell**.
You may use the first letter of each cell on the blanks instead of writing out the name. Each is all or nothing (.25 pts each)

1. Motor ____________________________
2. Sensory ___________________________
3. Dorsal Root ________________________
4. Ventral Root________________________
5. Dorsal Branch ______________________
6. Ventral Branch ______________________
7. Aids in conductivity _________________
8. Spinal Nerve________________________
9. Afferent ______________________
10. Efferent______________________
11. Somatic________________________
12. Visceral________________________
13. Peripheral Nervous System_______
14. Central Nervous System__________
15. Toward CNS___________________
16. Away from CNS________________

17. ___________

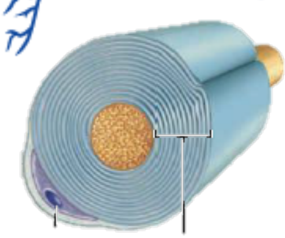


18. ________________



19. _________________

20. _________________



Integration

Print your names and table number on the BACK of the second page
DO NOT list the names of group members who are not present

Use the following case vignette to determine the answers to the questions:

A 28-year-old woman is admitted to the hospital after experiencing muscle pain and weakness. The patient reveals that she had been trying to recover from a Zika infection. You suspect Guillain-Barre Syndrome, an autoimmune condition associated with these types of infections that destroys Schwann cells by inflammation and demyelination of peripheral nerves and motor fibers.

You conduct electromyography (electrodes inserted into the muscle to measure nerve activity) and nerve conduction studies (electrodes on the skin above nerves that send a small shock through the nerve to measure the speed of the nerve).

Results from these tests are not consistent with Guillain-Barre Syndrome.

You return to the woman's room to give her the results of her tests when she informs you that she has been experiencing strong spasms in her extremities.

You do a quick physical exam and discover that the woman's muscle tone and reflexes are extremely heightened (sensitive / overactive).

To give the woman some comfort while you try to figure out what is going on you prescribe tubocurarine, a nondepolarizing drug which is a competitive antagonist for (competes with) Acetylcholine.

You review electromyography and nerve conduction studies results and perform new ones on the upper extremity only.

These tests, along with a few others, lead you to diagnose an upper motor neuron lesion in the lateral corticospinal tract. This area of the spinal cord is involved in voluntary motor control of the upper extremities. (Upper motor neurons are the neurons which descend from the brain to tell the motor neurons associated with spinal nerves – lower motor neurons – to send impulses to skeletal muscles.)

1. Where would the *remnants of destroyed Schwann cells* associated with motor neurons most likely be found?

   a. At neuromuscular junctions
   b. In the dermis superficial to muscles
   c. In epimysium
   d. In muscle cells
   e. In ventral grey matter of the spinal cord

2. What would be the expected results of a nerve conduction test for a patient that was *positively diagnosed* with Guillain-Barre Syndrome?

   a. Nerve impulses never reach the muscles
   b. Nerve impulses reach the muscles at an expected time
   c. Nerve impulses reach the muscles very early
   d. Nerve impulses reach the muscles very late

3. If this is truly an upper motor neuron disorder, what is the most likely result when the woman attempts to contract her posterior antebrachial muscles followed by direct nerve stimulation with an electrode?

   a. Unable with voluntary initiation / not produced with electrode
   b. Able with voluntary initiation / not produced with electrode
   c. Able with voluntary initiation / successfully produced with electrode
   d. Unable with voluntary initiation / successfully produced with electrode

4. Tubocurarine is referred to as a "nondepolarizing" drug because it prevents depolarization at what level?

   a. sarcomeres
   b. multipolar neuron dendrites
   c. the muscle cell
   d. multipolar neuron axons

5. Considering its effect, what commonly referred to group of drugs would tubocurarine belong to?

   a. Muscle Stimulants
   b. Anti-inflammatories
   c. Anesthetics
   d. Muscle relaxants

6. Which of the following would cause stiffness and spasms in the upper extremities?

    a. Severing the ventral root of a spinal nerve
    b. Inability of muscle cell organelles to reabsorb calcium ions
    c. Severing the ventral branch of a spinal nerve
    d. Prolonged stimulation of the dorsal root ganglion
    e. Prolonged simulation of the dorsal branch of a spinal nerve

7. Which of the following correctly describes the anatomical division of the nervous system which the neurons that are directly affected by this lesion belong to?

    a. Visceral
    b. Central
    c. Somatic
    d. Peripheral

8. The second electromyography is performed to evaluate the spinal nerves of the brachial plexus. In order to do this, you place an electrode into the posterior antebrachium (corresponds to craniolateral antebrachium in dogs). Which action should you ask the woman to perform in order to accurately evaluate the primary function of the muscles the electrode is in if it is acting as an agonist?

    a. Flex the elbow
    b. Extend the elbow
    c. Flex the shoulder
    d. Extend the wrist
    e. Extend the shoulder
    f. Flex the wrist

9. One reflex that you tested on this woman included applying sensory stimulation to the tendon of a muscle which crosses the flexor surface of the elbow joint, causing it to contract. If everything is normal, what should the woman do?

    a. Extend her elbow joint
    b. Flex her shoulder joint
    c. Extend her shoulder joint
    d. Flex her elbow joint

10. Because the woman's reflexes were heightened, you can determine that both of the following types of neurons associated with the spinal nerves are intact?

    a. bipolar / multipolar
    b. pseudounipolar / multipolar
    c. pseudounipolar / bipolar

APPENDIX B

CODED ALGORITHMS FOR MICROCONTROLLERS

For Sarcomere:

```
#include <Servo.h>
Servo Z1;  // create servo object to control a servo
Servo Z2;
int potpin = 0;  // analog pin used to connect the potentiometer
int val;    // variable to read the value from the analog pin

void setup()
{
  Z1.attach(9);  // attaches the servo on pin 9 to the servo object
  Z2.attach(10);
}

void loop()
{
  val = analogRead(potpin);  // reads the value of the potentiometer (value between 0 and 1023)
  val = map(val, 0, 1023, 0, 180);    / scale it to use it with the servo (value between 0 and 180)

  Z1.write(val);                // sets the servo position according to the scaled value
  Z2.write(val);

  delay(15);                    // waits for the servo to get there
}
```

For Model:

```
#include <Adafruit_NeoPixel.h> //include library to control the LED strips
#include <Servo.h>
#ifdef __AVR__
  #include <avr/power.h>
#endif
//Define pin numbers
  //Upper Motor Neurons
  #define BUTTON_U2 42 //const int BUTTON_U2 = 42; //BUTTON_U1 & LED_U1 are non-
functional (dead upper motor neuron)
    const int LED_U2 = 5;
      const int STRIP_U2 = 12;
        //to LED_M1

  //Motor Unit #1 has a ratio of 1:13
  #define BUTTON_M1 41 //const int BUTTON_M1 = 41;
```

```
  const int LED_M1 = 20;
    const int STRIP_M1 = 50;
      const int LED_A = 6;
      const int LED_M = 26;
      const int LED_KL = 19; //doubled up to free up a pin
      const int LED_X = 44;
      const int LED_NO = 27; //doubled up to free up a pin
      const int LED_P = 29;
      const int LED_D = 9;
      const int LED_Q = 30;
      const int LED_E = 10;
      const int LED_G = 15;
      const int LED_Y = 45;


  //Motor Unit #2 has a ratio of 1:4
  #define BUTTON_M2 31//const int BUTTON_M2 = 31; //Will also light up LED_M2
  const int LED_M2 = 13;
    const int STRIP_M2 = 2;
      const int LED_V = 38;
      const int LED_I = 17;
      const int LED_B = 7;
      const int LED_S = 35;

  //Motor Unit #3 has a ratio of 1:8
  #define BUTTON_M3 11 //const int BUTTON_M3 = 11;
  const int LED_M3 = 53;
    const int STRIP_M3 = 3;
      const int LED_C = 8;
      const int LED_F = 14;
      const int LED_H = 16;
      const int LED_J = 18;
      const int LED_R = 34;
      const int LED_T = 36;
      const int LED_U = 37;
      const int LED_W = 39;

const int PRESSURE_A1 = 47;
  const int STRIP_P1a = 40;
    const int LED_P1 = 21;
      const int STRIP_P1b = 46;

const int PRESSURE_A2 = 48;
  const int STRIP_P2a = 4;
    const int LED_P2 = 22;
      const int STRIP_P2b = 49;
```

```
  const int STRIP_P3a = 43;
    const int LED_P3 = 23;
      const int STRIP_P3b = 28;

// LED strip definition:
//  Parameter 1 = number of pixels in strip
//  Parameter 2 = Arduino pin number (most are valid)
//  Parameter 3 = pixel type flags, add together as needed:
  //Pseudounipolar Axons and Dendrites
    Adafruit_NeoPixel P1a = Adafruit_NeoPixel(24, STRIP_P1a, NEO_RGB + NEO_KHZ800);
//GSA Pseudounipolar dendrite LED strip has 30 pixels, should be attached to the right pin, and
is this type
    Adafruit_NeoPixel P1b = Adafruit_NeoPixel(3, STRIP_P1b, NEO_RGB + NEO_KHZ800);
//GSA Pseudounipolar axon LED strip has 30 pixels, should be attached to the right pin, and is
this type
    Adafruit_NeoPixel P2a = Adafruit_NeoPixel(25, STRIP_P2a, NEO_RGB + NEO_KHZ800);
//GSA Pseudounipolar dendrite LED strip has 30 pixels, should be attached to the right pin, and
is this type
    Adafruit_NeoPixel P2b = Adafruit_NeoPixel(5, STRIP_P2b, NEO_RGB + NEO_KHZ800);
//GSA Pseudounipolar axon LED strip has 30 pixels, should be attached to the right pin, and is
this type
    Adafruit_NeoPixel P3a = Adafruit_NeoPixel(27, STRIP_P3a, NEO_RGB + NEO_KHZ800);
//GSA Pseudounipolar dendrite LED strip has 30 pixels, should be attached to the right pin, and
is this type
    Adafruit_NeoPixel P3b = Adafruit_NeoPixel(2, STRIP_P3b, NEO_RGB + NEO_KHZ800);
//GSA Pseudounipolar axon LED strip has 30 pixels, should be attached to the right pin, and is
this type
  //Multipolar Axons
    Adafruit_NeoPixel M1 = Adafruit_NeoPixel(56, STRIP_M1, NEO_RGB + NEO_KHZ800);
//GSE Multipolar axon LED strip has 30 pixels, should be attached to the right pin, and is this
type
    Adafruit_NeoPixel M2 = Adafruit_NeoPixel(51, STRIP_M2, NEO_RGB + NEO_KHZ800);
//GSE Multipolar axon LED strip has 30 pixels, should be attached to the right pin, and is this
type
    Adafruit_NeoPixel M3 = Adafruit_NeoPixel(26, STRIP_M3, NEO_RGB + NEO_KHZ800);
//GSE Multipolar axon LED strip has 30 pixels, should be attached to the right pin, and is this
type
  //Upper Motor Neuron Axon
    Adafruit_NeoPixel U2 = Adafruit_NeoPixel(13, STRIP_U2, NEO_RGB + NEO_KHZ800);
//Upper Motor Neuron axon LED strip has 30 pixels, should be attached to the right pin, and is
this type

//Initialize/return pressure sensors and button to "off"
int switchState_A1 = 0; //initialize first skin pressure sensor to "off"
int switchState_A2 = 0; //initialize second skin pressure sensor to "off"
```

```
//int switchState_U2 = 0; //initialize push button to "off"
//int switchState_M1 = 0; //initialize push button to "off"
//int switchState_M2 = 0; //initialize push button to "off"
//int switchState_M3 = 0; //initialize push button to "off"

void setup()
{
  //Setup LEDs
   //for M1
    pinMode(LED_M1,OUTPUT);
    pinMode(LED_A,OUTPUT);
    pinMode(LED_NO,OUTPUT);
    pinMode(LED_P,OUTPUT);
    pinMode(LED_Q,OUTPUT);
    pinMode(LED_G,OUTPUT);
    pinMode(LED_M,OUTPUT);
    pinMode(LED_KL,OUTPUT);
    pinMode(LED_X,OUTPUT);
    pinMode(LED_E,OUTPUT);
    pinMode(LED_Y,OUTPUT);
    pinMode(LED_D,OUTPUT);
   //for M2 (no LED-M2 because BUTTON_M2 is directly connected to it) - added LED to 13
because had extra pins and wasn't working
    pinMode(LED_M2, OUTPUT);
    pinMode(LED_V,OUTPUT);
    pinMode(LED_I,OUTPUT);
    pinMode(LED_B,OUTPUT);
    pinMode(LED_S,OUTPUT);
   //for M3
    pinMode(LED_M3,OUTPUT);
    pinMode(LED_W,OUTPUT);
    pinMode(LED_C,OUTPUT);
    pinMode(LED_J,OUTPUT);
    pinMode(LED_F,OUTPUT);
    pinMode(LED_T,OUTPUT);
    pinMode(LED_R,OUTPUT);
    pinMode(LED_H,OUTPUT);
    pinMode(LED_U,OUTPUT);
   //Upper Motor Neuron
    pinMode(LED_U2,OUTPUT);
   //Pseudounipolar Somas
    pinMode(LED_P1,OUTPUT);
    pinMode(LED_P2,OUTPUT);
    pinMode(LED_P3,OUTPUT);
  //Setup LED Strips
   //Pseudounipolar Axons and Dendrites
```

```
  //P1
   P1a.begin();
   P1a.show();
   P1b.begin();
   P1b.show();
  //P2
   P2a.begin();
   P2a.show();
   P2b.begin();
   P2b.show();
  //P3
   P3a.begin();
   P3a.show();
   P3b.begin();
   P3b.show();
  //Multipolar Axons
   M1.begin();
   M1.show();
   M2.begin();
   M2.show();
   M3.begin();
   M3.show();
  //Upper Motor Neuron Axon
   U2.begin();
   U2.show();
 //Setup Buttons & Pressure Sensors
  pinMode(PRESSURE_A1, INPUT); //take in sensory information from the pressure sensor on
the skin
  pinMode(PRESSURE_A2, INPUT); //take in sensory information from the other pressure
sensor on the skin
  pinMode(BUTTON_M1, INPUT_PULLUP); //take in information from the push button located
beneath the multipolar neuron cell body
  pinMode(BUTTON_M2, INPUT_PULLUP); //take in information from the push button located
beneath the multipolar neuron cell body
  pinMode(BUTTON_M3, INPUT_PULLUP); //take in information from the push button located
beneath the multipolar neuron cell body
  pinMode(BUTTON_U2, INPUT_PULLUP); //take in information form the push button for the
upper motor neuron that works

 //Serial Port
 Serial.begin(9600); //open a serial port to check progress
}
void loop()
{
  //on/off depends on if the appropriate sensor or button is pressed
```

```
  switchState_A1 = digitalRead(PRESSURE_A1); //listen to the pressure sensor on the skin to know when to turn the sensory state on
  switchState_A2 = digitalRead(PRESSURE_A2); //listen to the pressure sensor on the skin to know when to turn the sensory state on
  //switchState_U2 = digitalRead(BUTTON_U2); //listen to the push button for working uppor motor neuron for the upper motor neuron
  //switchState_M1 = digitalRead(BUTTON_M1); //listen to the push button for M1 for Motor Unit 1
  //switchState_M2 = digitalRead(BUTTON_M2); //listen to the push button for M2 for Motor Unit 2
  //switchState_M3 = digitalRead(BUTTON_M3); //listen to the push button for M3 for Motor Unit 3

  int input = Serial.parseInt();

  if(digitalRead(BUTTON_U2)/*switchState_U2*/ == LOW)
  {
    Serial.println("Upper Motor Neuron Button Pressed!");
    Serial.println("1.) LED_U2 Lights Up");
      digitalWrite(LED_U2, HIGH);
      delay(2000);
    Serial.println("2.) LED_U2 Turns Off");
      digitalWrite(LED_U2, LOW);
    Serial.println("3.) STRIP_U2 Lights Up (Yellow) beginning to end"); //MYELINATED -> Same speed as M3 and P3
      colorWipe_U2(U2.Color(242,239,0),50);
      colorWipe_U2(U2.Color(0,0,0),0);
    Serial.println("4.) Motor Unit 1 Function");
      MotorUnit1();
  }

 else if(digitalRead(BUTTON_M1)/*switchState_M1*/ == LOW)
  {
    Serial.println("Motor Unit 1 Button Pressed!");
    Serial.println("1.) Motor Unit 1 Function");
      MotorUnit1();
  }
 else if(digitalRead(BUTTON_M2)/*switchState_M2*/ == LOW)
  {
    Serial.println("Motor Unit 2 Button Pressed!");
    Serial.println("1.) Motor Unit 2 Function");
      MotorUnit2();
  }
 else if(digitalRead(BUTTON_M3)/*switchState_M3*/ == LOW)
  {
    Serial.println("Motor Unit 3 Button Pressed!");
```

```
   Serial.println("1.) Motor Unit 3 Function");
     MotorUnit3();
  }
 else if(switchState_A1 == HIGH || switchState_A2 == HIGH)
  {
   Serial.println("Skin Touched!");
   Serial.println("1.) Afferent 1 Function, Afferent 2 Function & Afferent 3 Function");
     Afferent1();
     Afferent2();
     Afferent3();
  }
  else
  {
   Serial.println("waiting.....");
  }
}
//FUNCTIONS

// Fill the dots one after the other with a color
void colorWipe_M1(uint32_t c, uint8_t wait)
{
  for(uint16_t i=0; i<M1.numPixels(); i++)
  {
   M1.setPixelColor(i, c);
   M1.show();
   delay(wait);
  }
}
void colorWipe_M2(uint32_t c, uint8_t wait)
{
   for(uint16_t i=0; i<M2.numPixels(); i++)
  {
   M2.setPixelColor(i, c);
   M2.show();
   delay(wait);
  }
}
void colorWipe_M3(uint32_t c, uint8_t wait)
{
   for(uint16_t i=0; i<M3.numPixels(); i++)
  {
   M3.setPixelColor(i, c);
   M3.show();
   delay(wait);
  }
}
```

```
void colorWipe_U2(uint32_t c, uint8_t wait)
{
  for(uint16_t i=0; i<U2.numPixels(); i++)
  {
   U2.setPixelColor(i, c);
   U2.show();
   delay(wait);
  }
}
void colorWipe_P1a(uint32_t c, uint8_t wait)
{
  for(uint16_t i=0; i<P1a.numPixels(); i++)
  {
   P1a.setPixelColor(i, c);
   P1a.show();
   delay(wait);
  }
}
void colorWipe_P1b(uint32_t c, uint8_t wait)
{
  for(uint16_t i=0; i<P1b.numPixels(); i++)
  {
   P1b.setPixelColor(i, c);
   P1b.show();
   delay(wait);
  }
}
void colorWipe_P2a(uint32_t c, uint8_t wait)
{
  for(uint16_t i=0; i<P2a.numPixels(); i++)
  {
   P2a.setPixelColor(i, c);
   P2a.show();
   delay(wait);
  }
}
void colorWipe_P2b(uint32_t c, uint8_t wait)
{
  for(uint16_t i=0; i<P2b.numPixels(); i++)
  {
   P2b.setPixelColor(i, c);
   P2b.show();
   delay(wait);
  }
}
void colorWipe_P3a(uint32_t c, uint8_t wait)
```

```
{
  for(uint16_t i=0; i<P3a.numPixels(); i++)
  {
   P3a.setPixelColor(i, c);
   P3a.show();
   delay(wait);
  }
}
void colorWipe_P3b(uint32_t c, uint8_t wait)
{
  for(uint16_t i=0; i<P3b.numPixels(); i++)
  {
   P3b.setPixelColor(i, c);
   P3b.show();
   delay(wait);
  }
}

  void MotorUnit1()
  {
   Serial.println("------MOTOR UNIT 1 FUNCTION:");
   Serial.println("  1.) LED_M1 Lights Up");
    digitalWrite(LED_M1, HIGH);
    delay(2000);
   Serial.println("  2.) LED_M1 Turns Off");
    digitalWrite(LED_M1, LOW);
   Serial.println("  3.) STRIP_M1 Lights Up (Red) beginning to end"); //DAMAGED
SCHWANN CELLS -> SLOWER THAN M3, FASTER THAN M2
    colorWipe_M1(M1.Color(0,255,0),70);
    colorWipe_M1(M1.Color(0,0,0),0);
   Serial.println("  4.) All LEDs for Motor Unit 1 Light Up Simultaneously");
    digitalWrite(LED_A, HIGH);
    digitalWrite(LED_M, HIGH);
    digitalWrite(LED_KL,HIGH);
    digitalWrite(LED_X, HIGH);
    digitalWrite(LED_NO,HIGH);
    digitalWrite(LED_P, HIGH);
    digitalWrite(LED_D, HIGH);
    digitalWrite(LED_Q, HIGH);
    digitalWrite(LED_E, HIGH);
    digitalWrite(LED_G, HIGH);
    digitalWrite(LED_Y, HIGH);
    delay(2000);
   Serial.println("  6.) All LEDs for Motor Unit 1 Turn Off Simultaneously");
    digitalWrite(LED_A, LOW);
    digitalWrite(LED_M, LOW);
```

```
    digitalWrite(LED_KL, LOW);
    digitalWrite(LED_X, LOW);
    digitalWrite(LED_NO, LOW);
    digitalWrite(LED_P, LOW);
    digitalWrite(LED_D, LOW);
    digitalWrite(LED_Q, LOW);
    digitalWrite(LED_E, LOW);
    digitalWrite(LED_G, LOW);
    digitalWrite(LED_Y, LOW);
   Serial.println("--------------------------END FUNCTION--------------------------");
  }
  void MotorUnit2()
  {
   Serial.println("------MOTOR UNIT 2 FUNCTION:"); //pressing the button makes the LED light up already - didn't work, so added LED to pin 13
   Serial.println("  1.) LED_M2 Lights Up");
    digitalWrite(LED_M2, HIGH);
    delay(2000);
   Serial.println("  2.) LED_M2 Turns Off");
    digitalWrite(LED_M2, LOW);
   Serial.println("  1.) STRIP_M2 Lights Up (Red) beginning to end"); //UNMYLENATED -> SLOWEST
    colorWipe_M2(M2.Color(0,255,0),100);
    colorWipe_M2(M2.Color(0,0,0),0);
   Serial.println("  2.) All LEDs for Motor Unit 2 Light Up Simultaneously");
    digitalWrite(LED_V, HIGH);
    digitalWrite(LED_I, HIGH);
    digitalWrite(LED_B, HIGH);
    digitalWrite(LED_S, HIGH);
    delay(2000);
   Serial.println("  4.) All LEDs for Motor Unit 2 Turn Off Simultaneously");
    digitalWrite(LED_V, LOW);
    digitalWrite(LED_I, LOW);
    digitalWrite(LED_B, LOW);
    digitalWrite(LED_S, LOW);
   Serial.println("--------------------------END FUNCTION--------------------------");
  }
  void MotorUnit3()
  {
   Serial.println("------MOTOR UNIT 3 FUNCTION:");
   Serial.println("  1.) LED_M3 Lights Up");
    digitalWrite(LED_M3, HIGH);
    delay(2000);
   Serial.println("  2.) LED_M3 Turns Off");
    digitalWrite(LED_M3, LOW);
```

```
  Serial.println("  3.) STRIP_M3 Lights Up (Red) beginning to end"); //MYLENATED ->
FASTEST
    colorWipe_M3(M3.Color(0,255,0),40);
    colorWipe_M3(M3.Color(0,0,0),0);
  Serial.println("  4.) All LEDs for Motor Unit 3 Light Up Simultaneously");
    digitalWrite(LED_W, HIGH);
    digitalWrite(LED_C, HIGH);
    digitalWrite(LED_R, HIGH);
    digitalWrite(LED_J, HIGH);
    digitalWrite(LED_F, HIGH);
    digitalWrite(LED_T, HIGH);
    digitalWrite(LED_H, HIGH);
    digitalWrite(LED_U, HIGH);
    delay(2000);
  Serial.println("  6.) All LEDs for Motor Unit 3 Turn Off Simultaneously");
    digitalWrite(LED_W, LOW);
    digitalWrite(LED_C, LOW);
    digitalWrite(LED_R, LOW);
    digitalWrite(LED_J, LOW);
    digitalWrite(LED_F, LOW);
    digitalWrite(LED_T, LOW);
    digitalWrite(LED_H, LOW);
    digitalWrite(LED_U, LOW);
  Serial.println("-------------------------END FUNCTION-------------------------");
 }

 void Afferent1()
 {
  Serial.println("------AFFERENT 1 FUNCTION:");
  Serial.println("  1.) STRIP_P1a Lights Up (Blue) beginning to end"); //DAMAGED
SCHWANN CELLS -> SLOWER THAN P3, FASTER THAN P2
    colorWipe_P1a(P1a.Color(0,0,255),70);
    colorWipe_P1a(P1a.Color(0,0,0),0);
  Serial.println("  2.) LED_P1 Lights Up");
    digitalWrite(LED_P1, HIGH);
    delay(2000);
  Serial.println("  3.) LED_P1 Turns Off");
    digitalWrite(LED_P1, LOW);
  Serial.println("  4.) STRIP_P1b Lights Up (Blue) beginning to end"); //DAMAGED
SCHWANN CELLS -> SLOWER THAN M3, FASTER THAN M2
    colorWipe_P1b(P1b.Color(0,0,255),70);
    colorWipe_P1b(P1b.Color(0,0,0),0);
  Serial.println("-------------------------END FUNCTION-------------------------");
 }
 void Afferent2()
 {
```

```
  Serial.println("------AFFERENT 2 FUNCTION:");
  Serial.println("  1.) STRIP_P2a Lights Up (Blue) beginning to end"); //UNMYLENATED ->
SLOWEST
    colorWipe_P2a(P2a.Color(0,0,255),100);
    colorWipe_P2a(P2a.Color(0,0,0),0);
  Serial.println("  2.) LED_P2 Lights Up");
    digitalWrite(LED_P2, HIGH);
    delay(2000);
  Serial.println("  3.) LED_P2 Turns Off");
    digitalWrite(LED_P2, LOW);
  Serial.println("  4.) STRIP_P2b Lights Up (Blue) beginning to end"); //UNMYLENATED ->
SLOWEST
    colorWipe_P2b(P2b.Color(0,0,255),100);
    colorWipe_P2b(P2b.Color(0,0,0),0);
  Serial.println("-------------------------END FUNCTION-------------------------");
 }
 void Afferent3()
 {
  Serial.println("------AFFERENT 3 FUNCTION:");
  Serial.println("  1.) STRIP_P3a Lights Up (Blue) beginning to end"); //MYLENATED ->
FASTEST
    colorWipe_P3a(P3a.Color(0,0,255),40);
    colorWipe_P3a(P3a.Color(0,0,0),0);
  Serial.println("  2.) LED_P3 Lights Up");
    digitalWrite(LED_P3, HIGH);
    delay(2000);
  Serial.println("  3.) LED_P3 Turns Off");
    digitalWrite(LED_P3, LOW);
  Serial.println("  4.) STRIP_P3b Lights Up (Blue) beginning to end"); //MYLENATED ->
FASTEST
    colorWipe_P3b(P3b.Color(0,0,255),40);
    colorWipe_P3b(P3b.Color(0,0,0),0);
  Serial.println("-------------------------END FUNCTION-------------------------");
 }
```

APPENDIX C

ASSESSMENTS

Surveys

Attitudes and Motivations for Education – Preliminary Survey

We are conducting a student survey on attitudes towards learning. Your voluntary participation is requested. Our questionnaire will take approximately 10 minutes to complete. Your responses will be kept confidential. You may choose not to answer any or all of the questions on the questionnaire even after you begin the survey. Please answer the following honestly and to the best of your ability. This survey is voluntary and confidential and will not affect your grade in any way.

UIN: ____________________________ **Age:** ________ **Gender:** ________________

Expected Year of Graduation: ________________ **Current GPA:** ____________

Circle the statement that best describes you:

A. This is my first time taking VIBS 305
B. This is my second attempt at VIBS 305
C. This is my third attempt at VIBS 305

Have you taken an anatomy course before this?
(i.e. in high school, community college, or another university)

A. Yes
B. No

If you chose "Yes" on the previous question, did the course include any dissection?

A. Yes *(Species dissected ______________________)*
B. No

What are your current career goals?

A. Pharmacy
B. Medicine
C. Veterinary Medicine
D. Dental
E. Nurse
F. Physician Assistant
G. Physical Therapy
H. Graduate School
I. Undecided
J. Other *(please list ____________________________________)*

Which of the following hobbies do you enjoy? *(Check all that apply)*

- ☐ Video or Computer Games
- ☐ Drawing/Painting
- ☐ Sculpting
- ☐ Working Out
- ☐ Playing Sports
- ☐ Cooking
- ☐ Knitting
- ☐ Learning
- ☐ Photography
- ☐ Dance
- ☐ Gardening
- ☐ Watch Movies/TV Shows
- ☐ Other *(please List _________________)*

Rate the following goals for this course in order from ***most important (1)*** to ***least important (6):***

_____Score higher than the average
_____Get an "A"
_____Learn the material
_____Get the highest score in the class
_____Appear smart to my peers
_____Pass the course

To what extent do you agree with these statements?	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
My study plan for this course is different than how I have studied for life science courses in the past.					
In general, I enjoy studying.					
I enjoy studying for life science courses more than studying for other courses.					
In general, I enjoy learning.					
I enjoy learning life science more than other topics.					
The most challenging courses are the most enjoyable.					
I learn the most in courses that challenge me the most.					
When preparing for a test, I prefer to memorize information rather than practice application.					
I learn more from memorization than from practicing application of information.					

How important are the following for you?	Not Important	Somewhat Important	Undecided	Important	Very Important
Working with living organisms rather than objects.					
Helping other people.					
Working with animals.					
Working with something that is easy and simple.					
Building or repairing things using my hands.					
Working creatively.					
Working artistically.					
Using my specific talents and abilities.					
Making, designing or inventing new things.					
Coming up with new ideas.					
Making my own decisions.					
Working independently of other people.					
Working with something important and meaningful.					
Working with something that fits my values.					
Earn a lot of money.					
Having plenty of time for interests and hobbies.					
Becoming or being the boss.					
Developing and improving knowledge and abilities.					
Working as part of a team.					

To what extent do you agree with these statements?	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
The things that I have learned in my science courses will be helpful in everyday life.					
I believe that what I have learned in my science courses will improve my career opportunities.					
Learning about life science increases my curiosity about things that we cannot yet explain.					

How often have you done the following activities?	Never	Sometimes	Undecided	Often	Very Often
Read about nature or science in books or magazines.					
Watched TV shows, documentaries, or movies about nature and/or science.					

Attitudes and Motivations for Education & Interaction with a Physical Model

We are conducting a student survey on attitudes towards learning as well as your experience interacting with a physical model. Your voluntary participation is requested. Our questionnaire will take approximately 10 minutes to complete. Your responses will be kept confidential. You may choose not to answer any or all of the questions on the questionnaire even after you begin the survey. Please answer the following honestly and to the best of your ability. This survey is voluntary and confidential and will not affect your grade in any way.

UIN: ______________________________

Rate the following goals for this course in order from ***most important (1)*** to ***least important (6):***

_____Score higher than the average

_____Get an "A"

_____Learn the material

_____Get the highest score in the class

_____Appear smart to my peers

_____Pass the course

I enjoyed using the physical model to study...	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
muscle actions.					
neuron function.					
skeletal muscle organization. (i.e. myofibers, fascicles, etc.)					
sarcomeres.					

I enjoyed...	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
completing the activity with the physical model.					
working with my group while interacting with the physical model.					

The physical model helped me to understand....	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
the concept of fixation of a joint.					
flexion and extension of joints.					
actions of muscle groups.					
the concept of efferent and afferent impulses.					
the differences between motor and sensory neurons.					
the location of neuronal cell bodies and axons.					
the axon to muscle cell ratio and how it affects control.					
the concept of all-or-none contraction.					
how a neuron gets from the central nervous system to an individual muscle cell.					
the connective tissue layers associated with skeletal muscle.					
the organization of muscle cells within a muscle.					
how the force of contraction is conveyed to tendons and bones.					
how thick and thin filaments interact during contraction.					
the organization of a sarcomere.					
the underlying mechanism of contraction and relaxation.					
at least one other concept related to functional musculoskeletal anatomy not mentioned here.					

The physical model helped me to be better able to...	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
mentally visualize contraction and relaxation of muscles.					
mentally use the location of a muscle relative to the flexor angle to deduce the muscle's action.					
see specific origins and insertions.					
see actions of specific muscles.					
Compared to my typical study method, the physical model helped me to learn the material...	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
in a shorter amount of time.					
with less effort.					
more thoroughly and in depth.					
I would use this method, or a similar method, to study....	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
other concepts in this course.					
for other life science courses.					
I benefited from...	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
being able to touch and manipulate the model.					
simulating muscle movement by pulling strings.					
seeing abstract concepts demonstrated.					
working in a group.					
Overall...	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
my experience interacting with this model has influenced my study plan for the rest of the course.					
interacting with the model was easy and intuitive.					
I think I benefited from working with the physical model.					

Attitudes and Motivations for Education – Checkpoint Survey

We are conducting a student survey on attitudes towards learning. Your voluntary participation is requested. Our questionnaire will take approximately 10 minutes to complete. Your responses will be kept confidential. You may choose not to answer any or all of the questions on the questionnaire even after you begin the survey. Please answer the following honestly and to the best of your ability. This survey is voluntary and confidential and will not affect your grade in any way.

UIN: ___________________________

Rate the following goals for this course in order from ***most important (1)*** to ***least important (6):***

_____Score higher than the average

_____Get an "A"

_____Learn the material

_____Get the highest score in the class

_____Appear smart to my peers

_____Pass the course

To what extent do you agree with these statements?	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
My study method for this past exam was significantly different from previous exams in this course.					
I plan to significantly change my study method in preparation for the next exam.					

Attitudes and Motivations for Education – Final Survey

We are conducting a student survey on attitudes towards learning. Your voluntary participation is requested. Our questionnaire will take approximately 10 minutes to complete. Your responses will be kept confidential. You may choose not to answer any or all of the questions on the questionnaire even after you begin the survey. Please answer the following honestly and to the best of your ability. This survey is voluntary and confidential and will not affect your grade in any way.

UIN: ______________________________

Rate the following goals for ***future courses*** in order from ***most important (1)*** to ***least important (6):***

_____Score higher than the average

_____Get an "A"

_____Learn the material

_____Get the highest score in the class

_____Appear smart to my peers

_____Pass the course

To what extent do you agree with these statements?	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
I enjoyed studying for this course.					
I mostly practiced application and critical thinking					
I mostly used memorization when studying for this course.					
Studying for this course was enjoyable when I practiced applying and critically thinking about the information.					
Studying for this course was enjoyable when I memorized terms and facts.					
I will be able to use the information I learned in this course in my future.					
In general, I enjoy studying.					
I enjoy studying for life science courses more than studying for other courses.					
In general, I enjoy learning.					
I enjoy learning life science more than other topics.					
When preparing for a test, I prefer to memorize information rather than practice application.					
I learn more from memorization than from practicing application of information.					

How important are the following for you?	**Not Important**	**Somewhat Important**	**Undecided**	**Important**	**Very Important**
Working with living organisms rather than objects.					
Helping other people.					
Working with animals.					
Working with something that is easy and simple.					
Building or repairing things using my hands.					
Working creatively.					
Working artistically.					
Using my specific talents and abilities.					
Making, designing or inventing new things.					
Coming up with new ideas.					
Making my own decisions.					
Working independently of other people.					
Working with something important and meaningful.					

How important are the following for you?	**Not Important**	**Somewhat Important**	**Undecided**	**Important**	**Very Important**
Working with something that fits my values.					
Earn a lot of money.					
Having plenty of time for interests and hobbies.					
Becoming or being the boss.					
Developing and improving knowledge and abilities.					
Working as part of a team.					

To what extend do you agree with these statements?	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
The things that I have learned in my science courses will be helpful in everyday life.					
I believe that what I have learned in my science courses will improve my career opportunities.					
Learning about life science increases my curiosity about things that we cannot yet explain.					

Throughout this semester, how often have you done the following activities?	**Never**	**Sometimes**	**Undecided**	**Often**	**Very Often**
Read about nature or science in books or magazines.					
Watched TV shows, documentaries, or movies about nature and/or science.					

Attitudes and Motivations for Education – Future Course Survey

We are conducting a student survey on attitudes towards learning. Your voluntary participation is requested. Our questionnaire will take approximately 10 minutes to complete. Your responses will be kept confidential. You may choose not to answer any or all of the questions on the questionnaire even after you begin the survey. Please answer the following honestly and to the best of your ability. This survey is voluntary and confidential and will not affect your grade in any way.

UIN: ____________________________

Rate the following goals for ***future courses*** in order from ***most important (1)*** to ***least important (6):***

_____Score higher than the average

_____Get an "A"

_____Learn the material

_____Get the highest score in the class

_____Appear smart to my peers

_____Pass the course

To what extent do you agree with these statements?	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
I enjoyed studying for this course.					
I mostly practiced application and critical thinking					
I mostly used memorization when studying for this course.					
Studying for this course was enjoyable when I practiced applying and critically thinking about the information.					
Studying for this course was enjoyable when I memorized terms and facts.					
I will be able to use the information I learned in this course in my future.					
In general, I enjoy studying.					
I enjoy studying for life science courses more than studying for other courses.					
In general, I enjoy learning.					
I enjoy learning life science more than other topics.					
When preparing for a test, I prefer to memorize information rather than practice application.					
I learn more from memorization than from practicing application of information.					

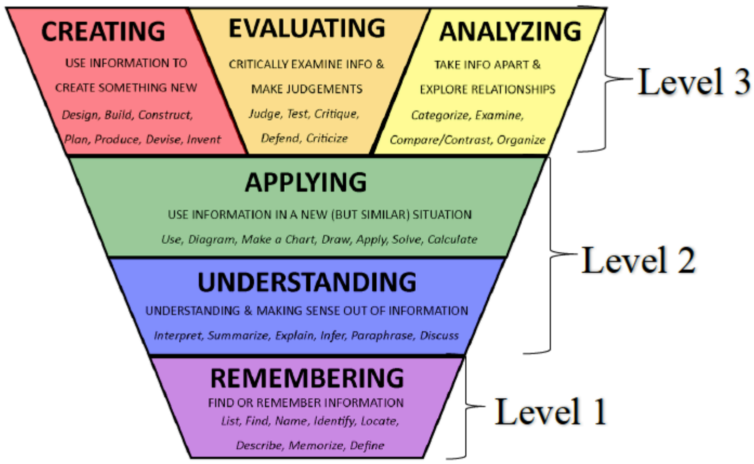
How important are the following for you?	**Not Important**	**Somewhat Important**	**Undecided**	**Important**	**Very Important**
Working with something that is easy and simple.					
Using my specific talents and abilities.					
Making, designing or inventing new things.					
Making my own decisions.					
Working independently of other people.					
Working with something important and meaningful.					

How important are the following for you?	**Not Important**	**Somewhat Important**	**Undecided**	**Important**	**Very Important**
Earn a lot of money.					
Having plenty of time for interests and hobbies.					
Becoming or being the boss.					
Developing and improving knowledge and abilities.					

To what extend do you agree with these statements?	**Strongly Agree**	**Agree**	**Undecided**	**Disagree**	**Strongly Disagree**
The things that I have learned in my science courses will be helpful in everyday life.					
I believe that what I have learned in my science courses will improve my career opportunities.					
Learning about life science increases my curiosity about things that we cannot yet explain.					

Throughout this semester, how often have you done the following activities?	**Never**	**Sometimes**	**Undecided**	**Often**	**Very Often**
Read about nature or science in books or magazines.					
Watched TV shows, documentaries, or movies about nature and/or science.					

In-Lab Observations and Informal Interviews: Student Engagement, Motivation & Critical Thinking



UGTA__________________

Table #__________

Week_______

During this week, how often did you observe students asking questions at each of these levels?	***Never***	***Sometimes***	***Undecided***	***Often***	***Very Often***
Level 1 Questions *(list, find, name, identify, locate)*					
Level 2 Questions *(draw, apply, explain, infer, etc.)*					
Level 3 Questions *(design, test, categorize, compare, etc.)*					
To what extent do you agree with these statements?	***Strongly agree***	***Agree***	***Undecided***	***Disagree***	***Strongly Disagree***
Students were able to answer level 1 questions with confidence.					
Students were able to answer level 2 questions with confidence.					
Students were able to answer level 3 questions with confidence.					
Students asked upper-level questions (levels 2 & 3) without prompting.					
Students seemed excited about and interested in the material.					
Students only wanted to know information relevant to the upcoming tests.					
I believe students are studying efficiently outside of class.					

Please include any other comments or observations that you made during the past week concerning the students' engagement, motivation, and/or critical thinking.

____

____

____

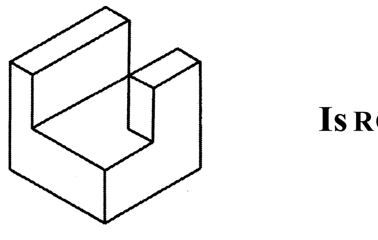
Revised Purdue Spatial Visualization Tests: Visualization of Rotations (Revised PSVT:R)

So Yoon   Yoon

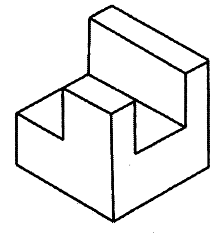
- DO NOT open this booklet until you are instructed to do so.
- DO NOT make any marks in this booklet.
- MARK your answers on the separate answer sheet.

DIRECTIONS

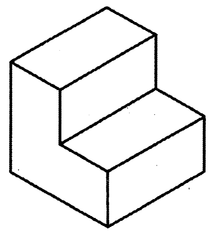
This test consists of 30 questions designed to see how well you can visualize the rotation of three-dimensional objects. Shown below is an example of the type of question included in the second section.



IS ROTATED TO

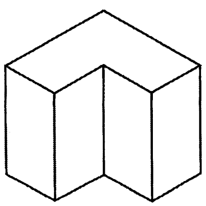


As

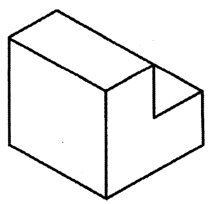


IS ROTATED TO

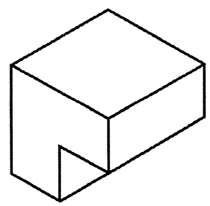
A



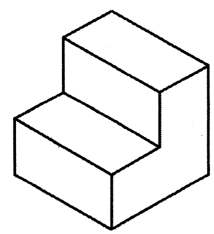
B



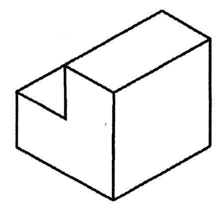
C



D



E



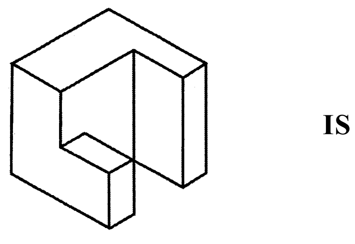
You are to:

1. study how the object in the top line of the question is rotated;
2. picture in your mind what the object shown in the middle line or the question looks like when rotated in exactly the same manner;
3. select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.

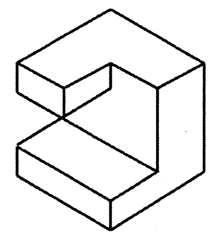
What is the correct answer to the example shown above?

Answers A, B, C, and E are wrong. Only drawing D looks like the object rotated according to the given rotation. Remember that each question has only one correct answer.

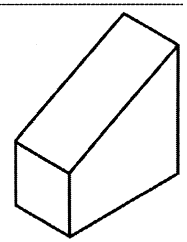
Now look at the next example shown below and try to select the drawing that looks like the object in_the correct position when the given rotation is applied.



IS ROTATED TO

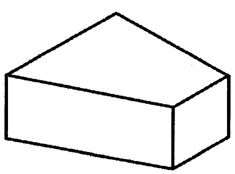


As

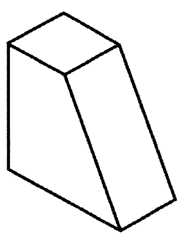


Is ROTATED To

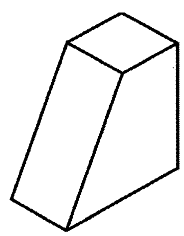
A



B



C



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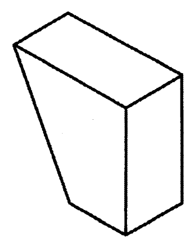

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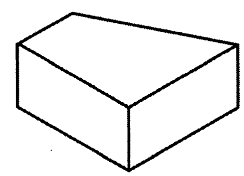
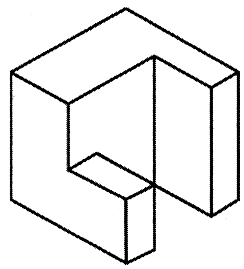


Notice that the given rotation in this example is more complex. The correct answer for this example is B.

- DO NOT make any marks in this booklet.
- Mark your answers on the separate answer sheet.
- You will be told when to begin.

1



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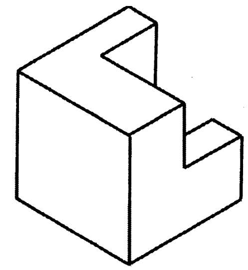

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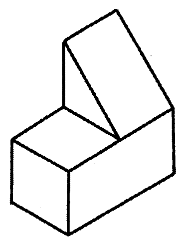

Is ROTATED To

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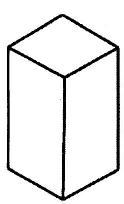

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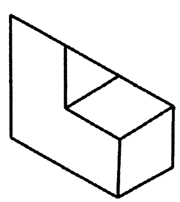

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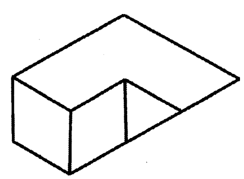

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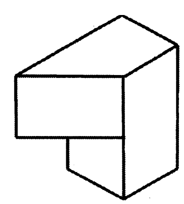

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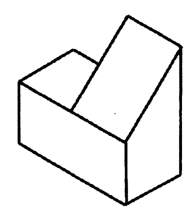

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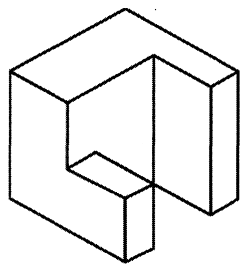

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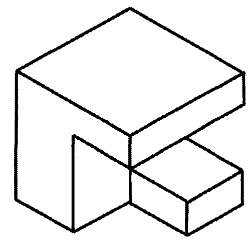

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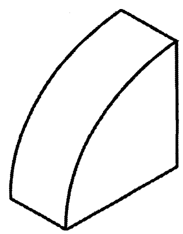

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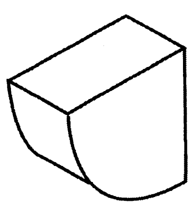

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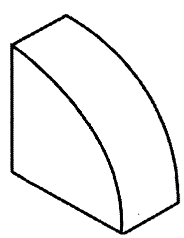

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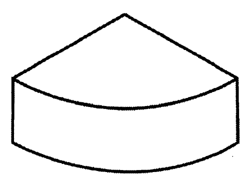

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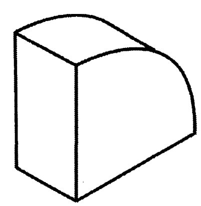

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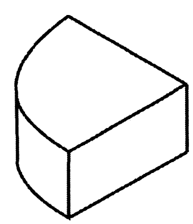

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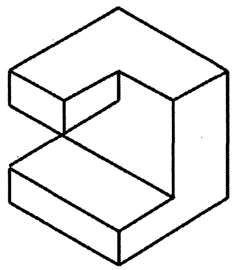

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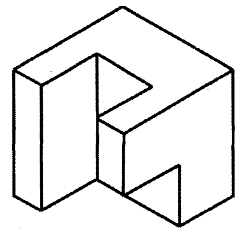

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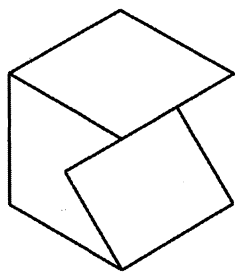

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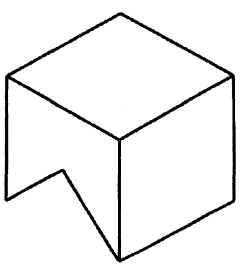

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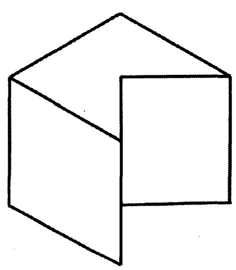

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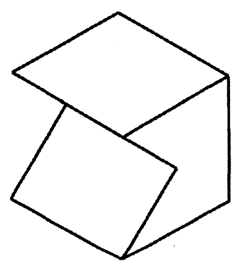

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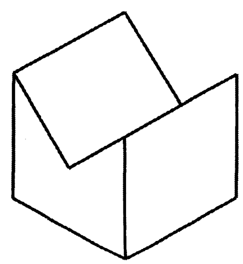

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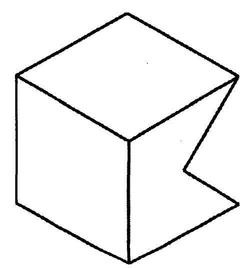

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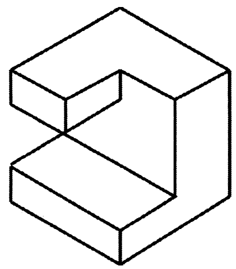

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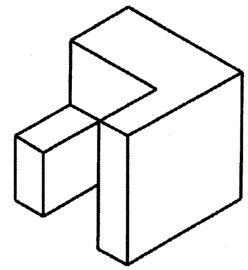

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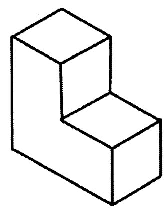

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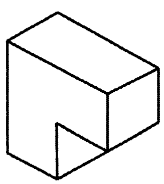

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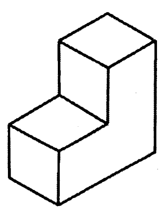

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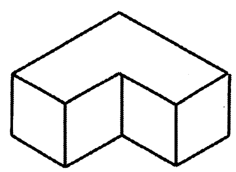

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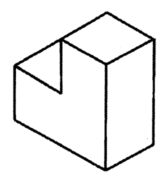

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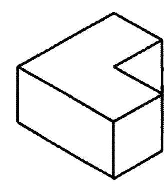

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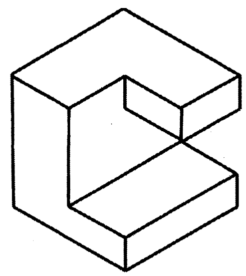

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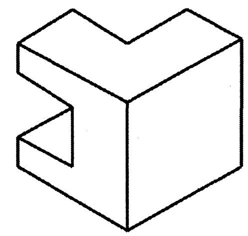

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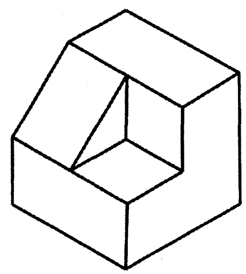

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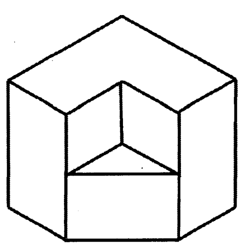

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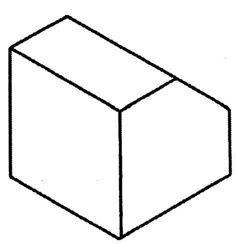

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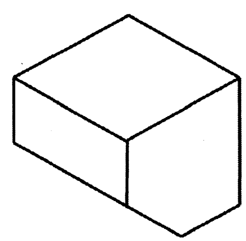

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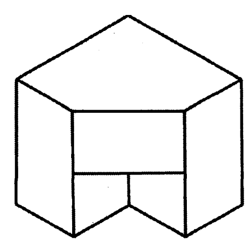

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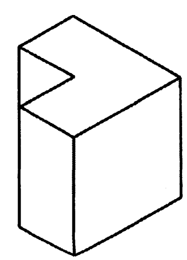

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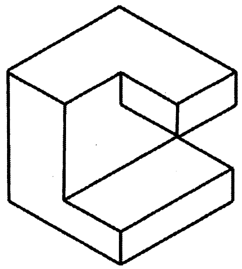

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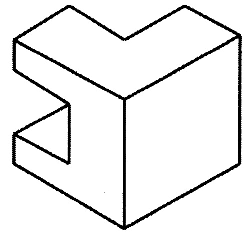

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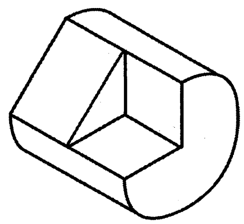

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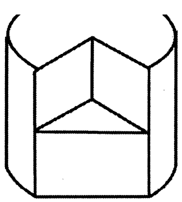

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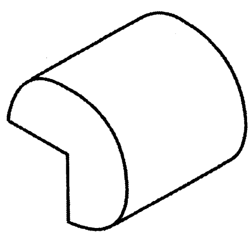

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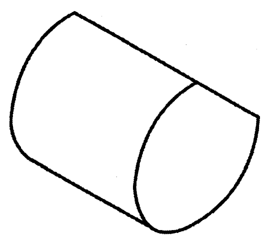

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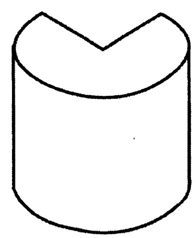

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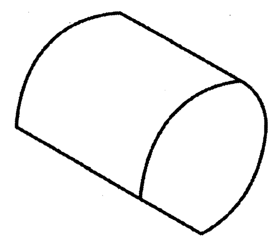

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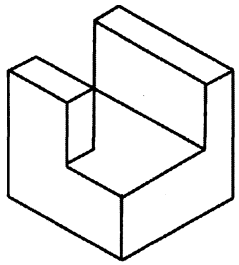

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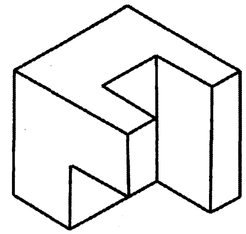

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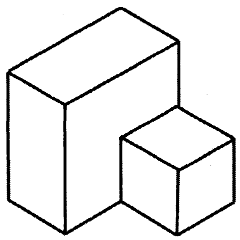

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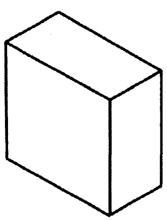

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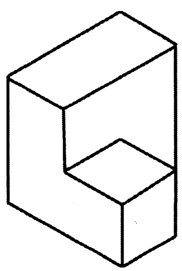

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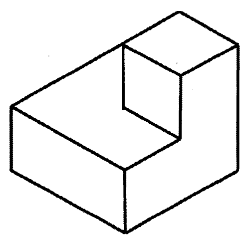

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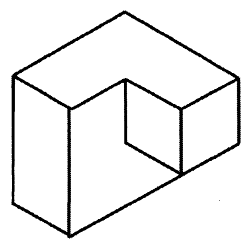

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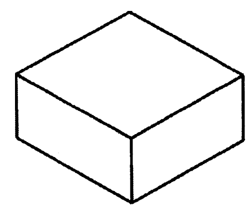

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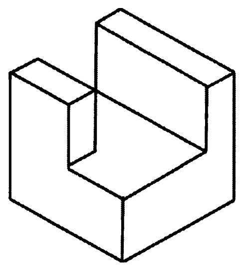

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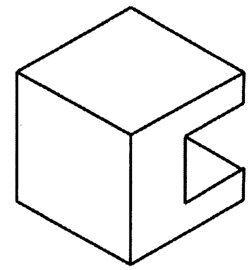

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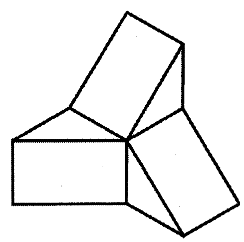

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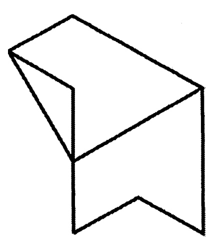

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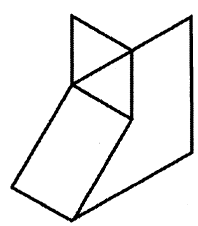

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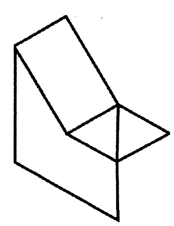

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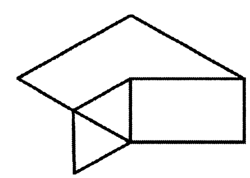

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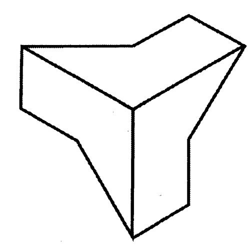

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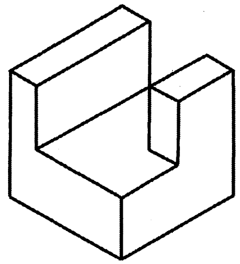

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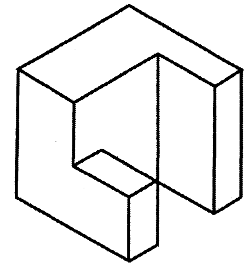

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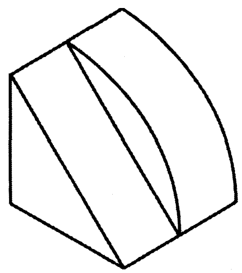

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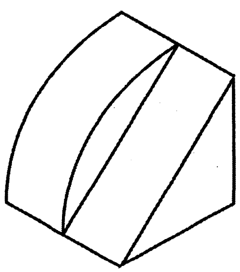

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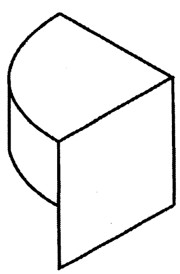

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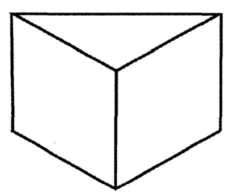

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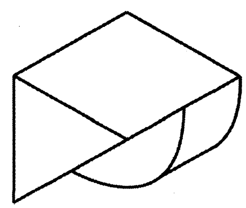

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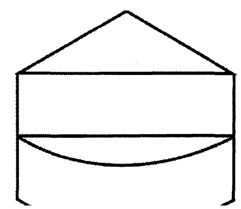

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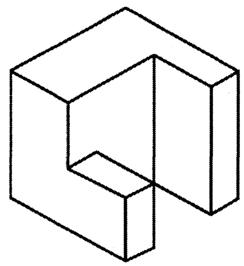
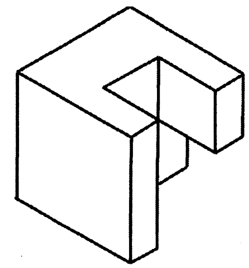
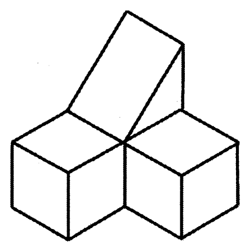
 Is rotated To 

As  Is rotated To

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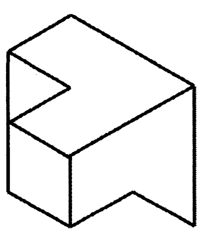

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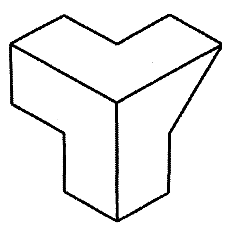

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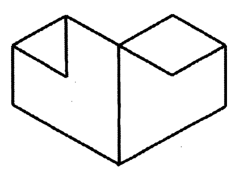

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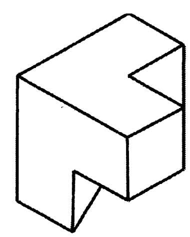

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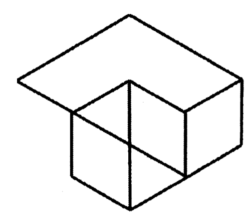

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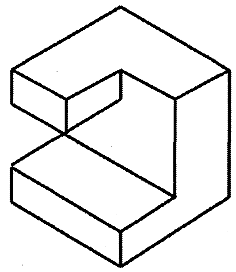

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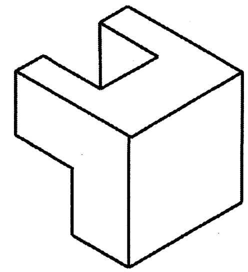

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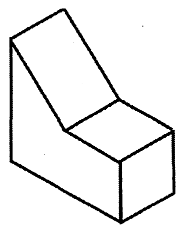

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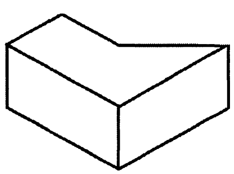

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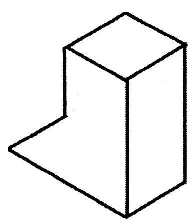

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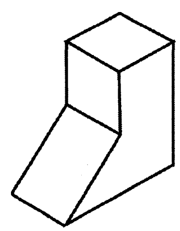

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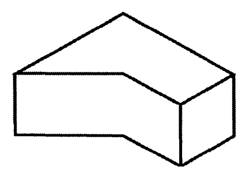

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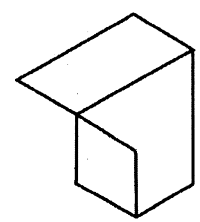

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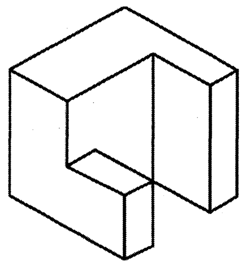

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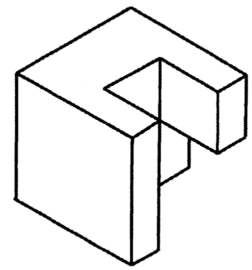

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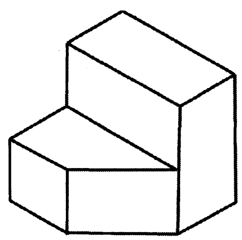

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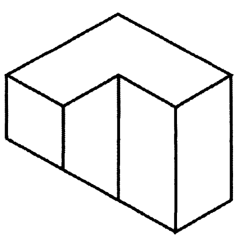

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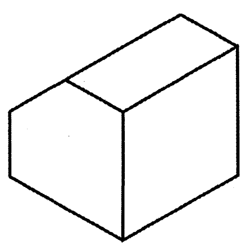

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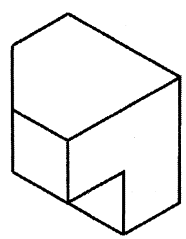

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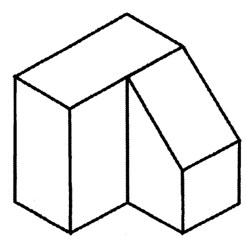

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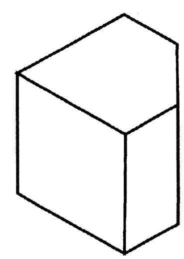

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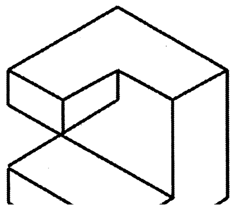

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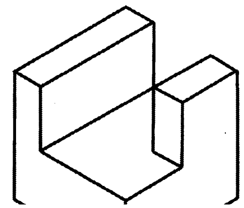

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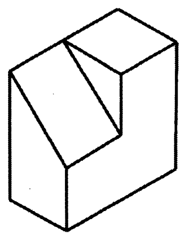

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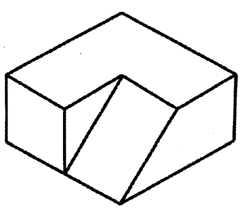

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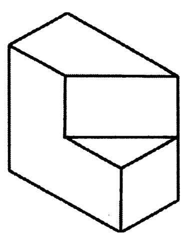

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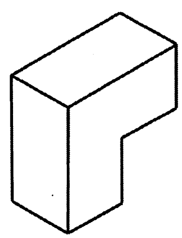

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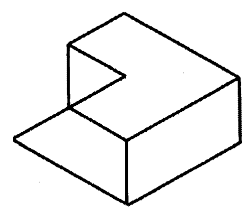

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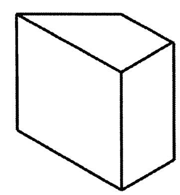

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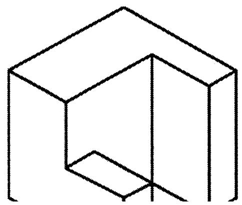

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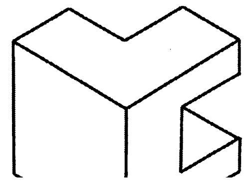

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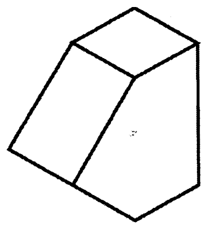

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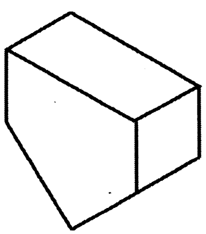

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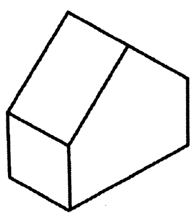

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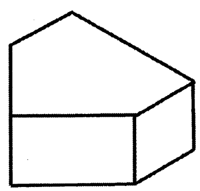

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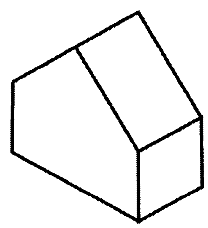

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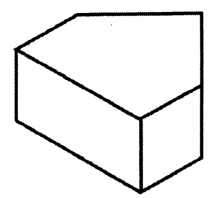

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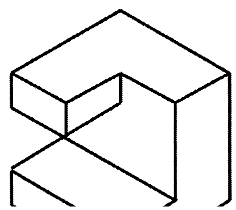
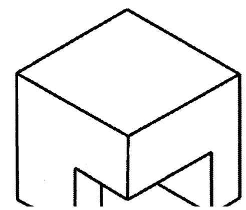
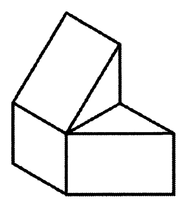
 Is rotated To 

As  Is rotated To

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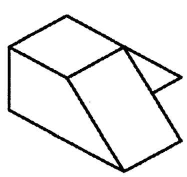

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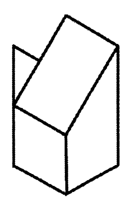

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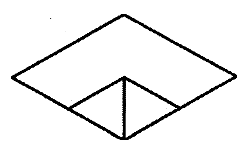

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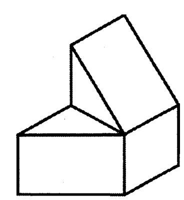

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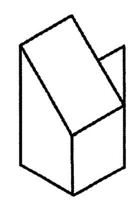

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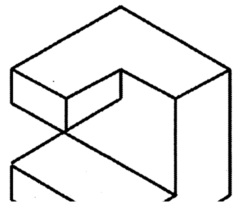

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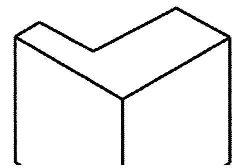

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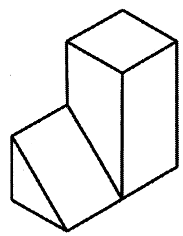

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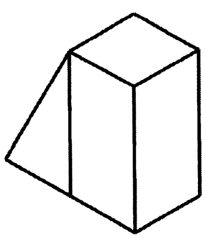

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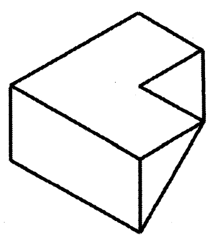

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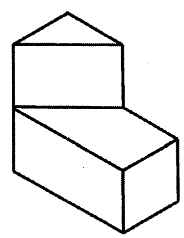

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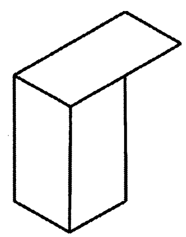

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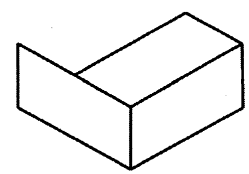

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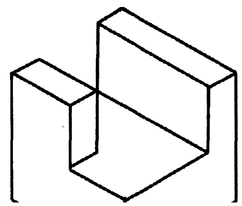

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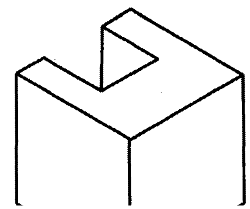

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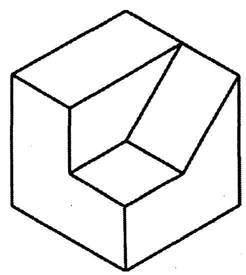

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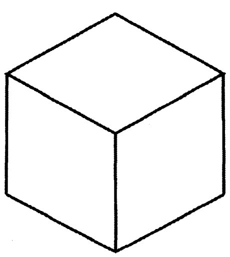

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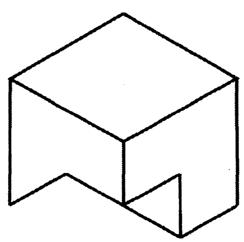

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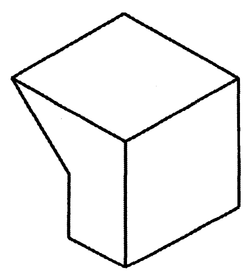

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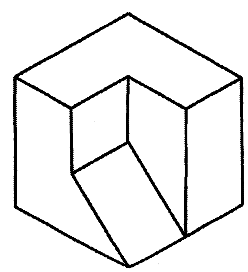

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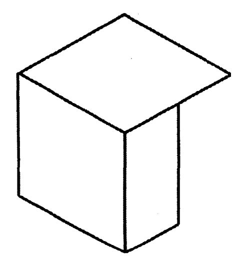

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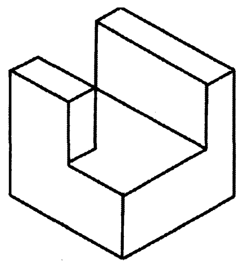

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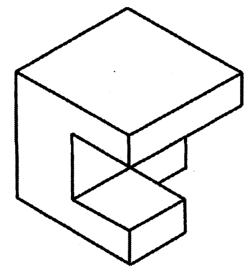

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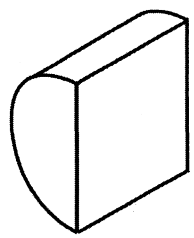

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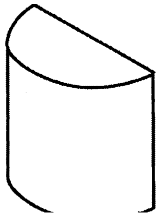

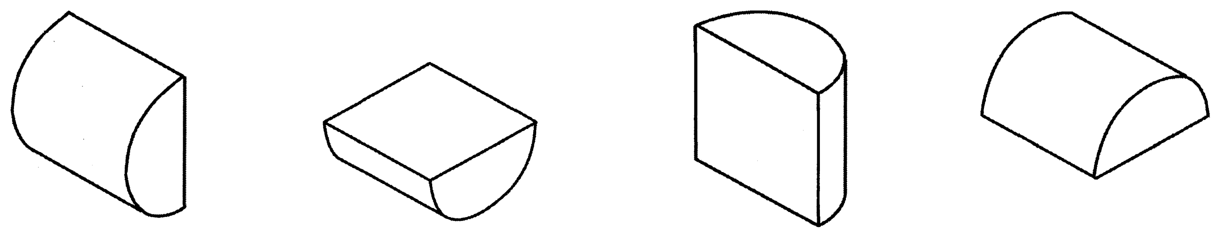

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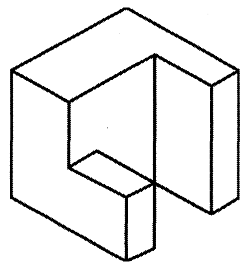

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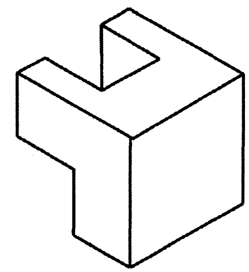

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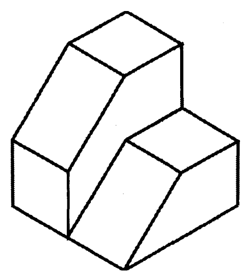

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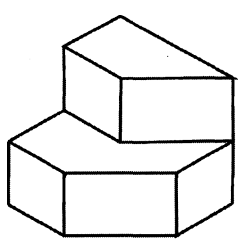

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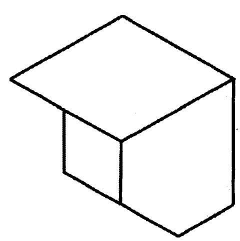

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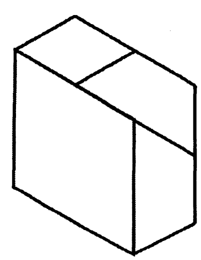

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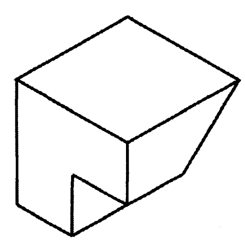

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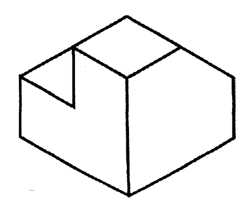

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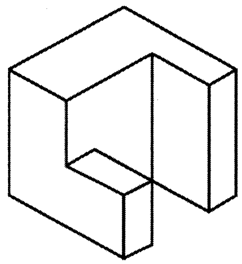
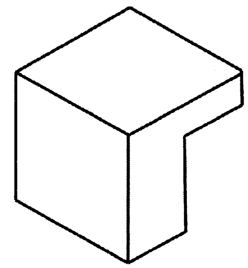
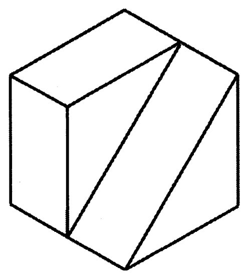
 IS ROTATED TO 

AS  IS ROTATED TO

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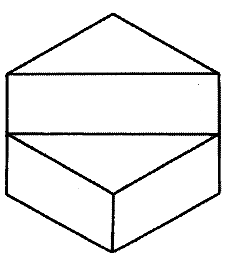

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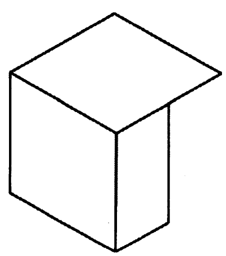

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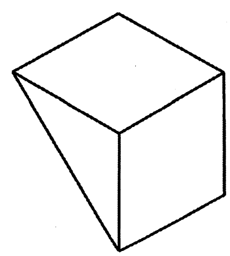

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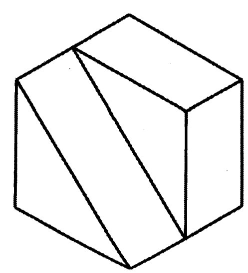

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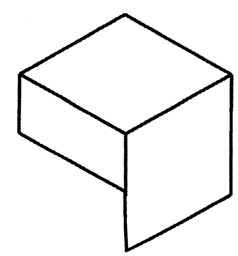

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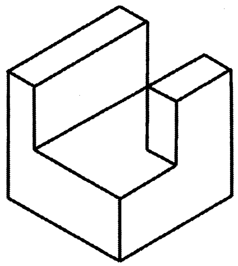

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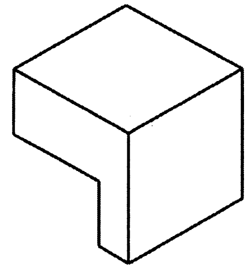

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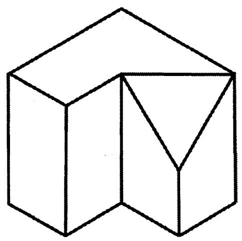

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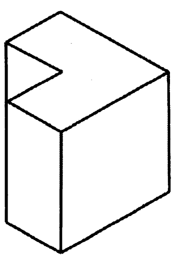

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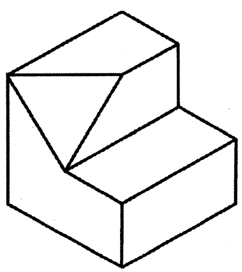

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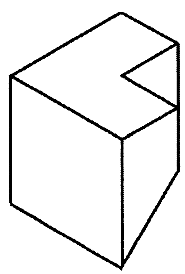

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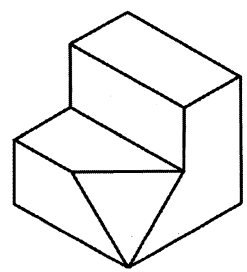

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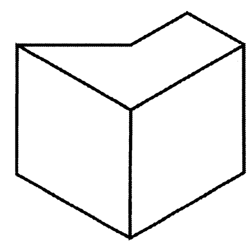

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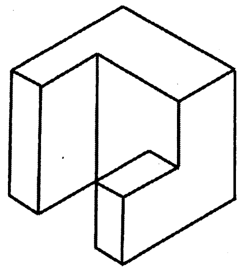

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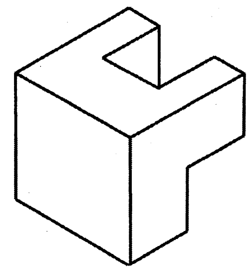

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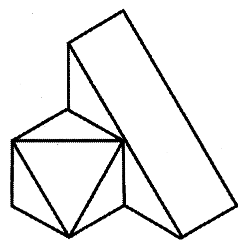

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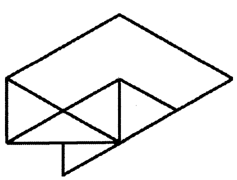

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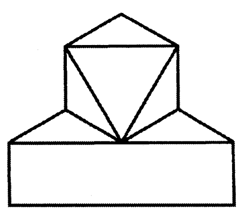

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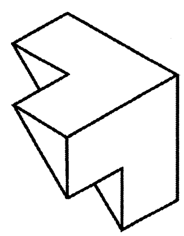

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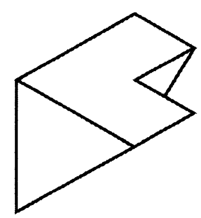

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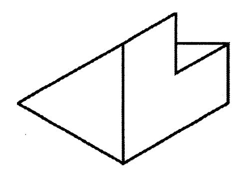

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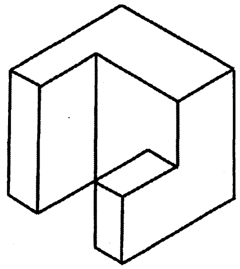

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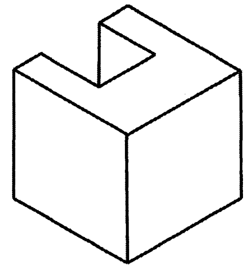

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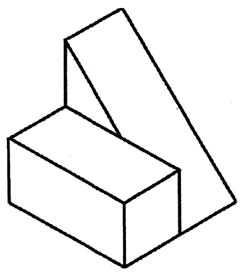

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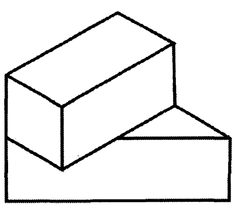

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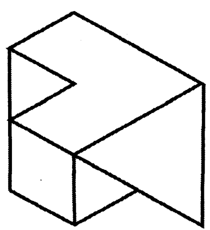

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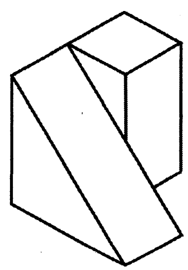

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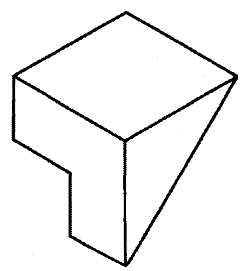

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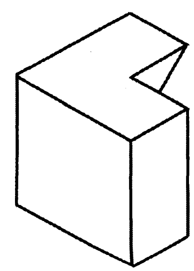

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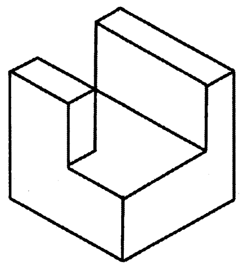

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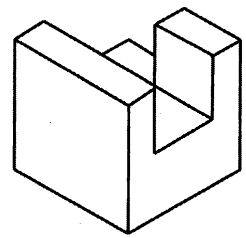

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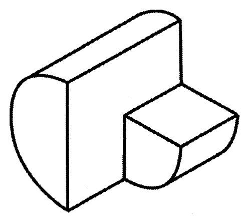

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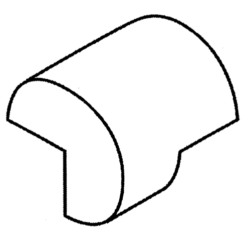

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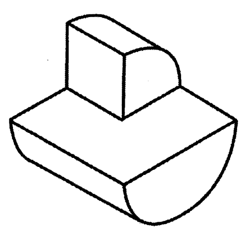

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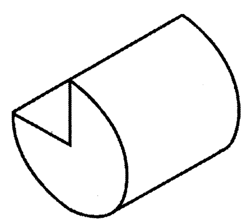

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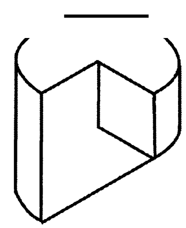

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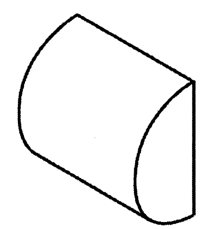

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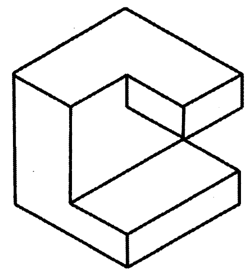

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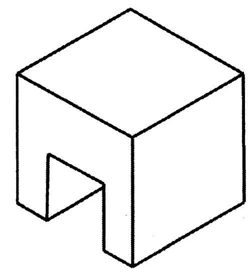

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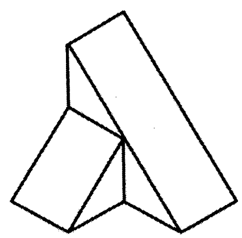

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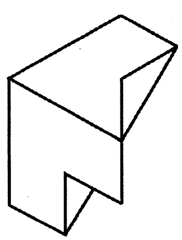

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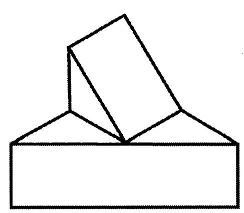

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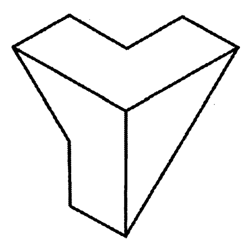

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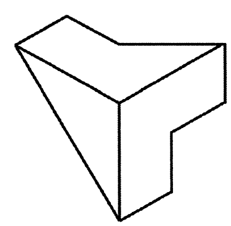

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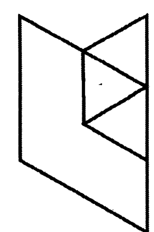

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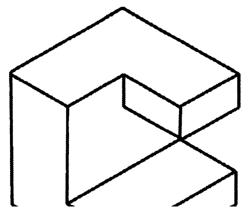

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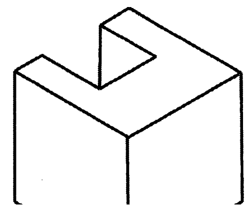

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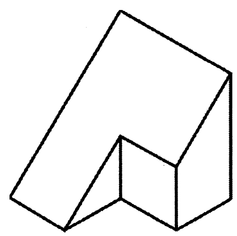

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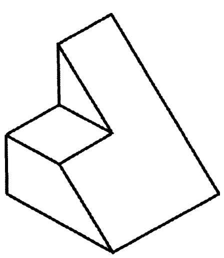

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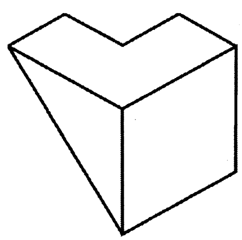

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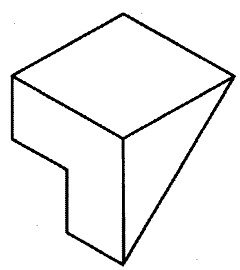

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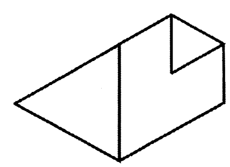

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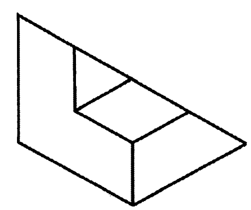

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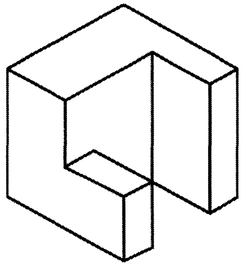

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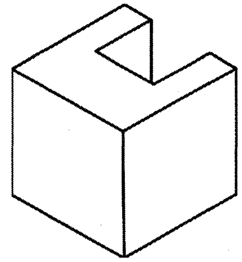

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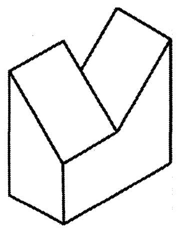

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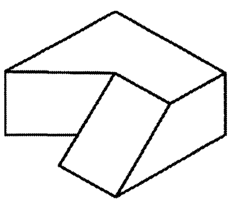

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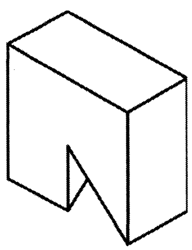

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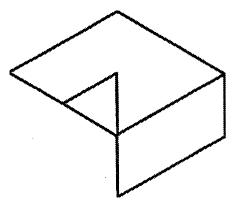

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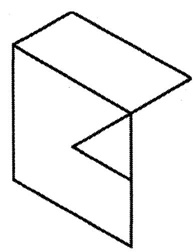

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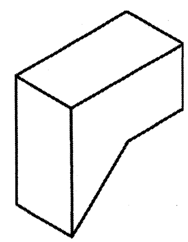

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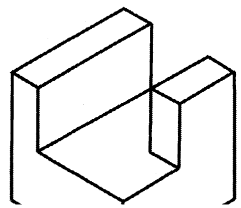

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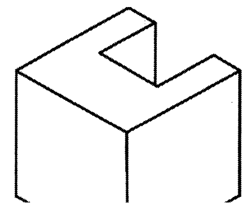

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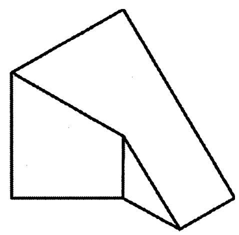

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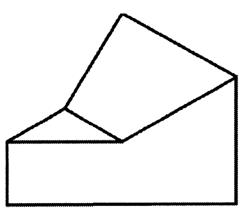

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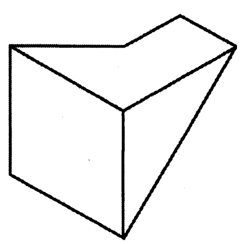

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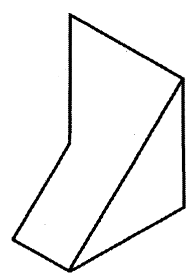

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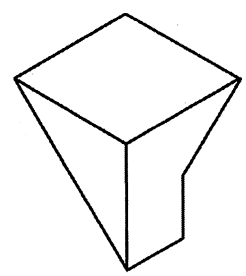

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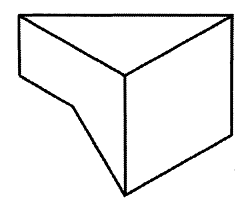

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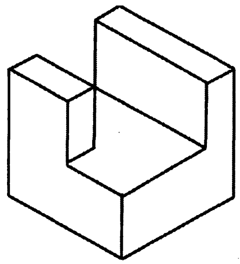
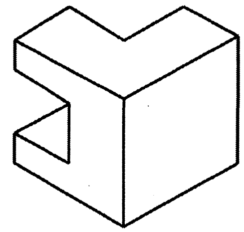
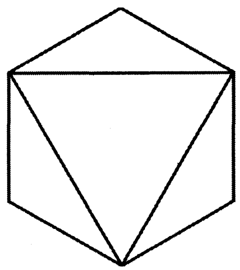


Is ROTATED To

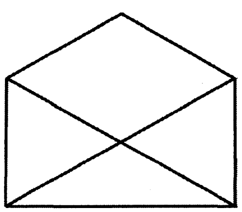


As

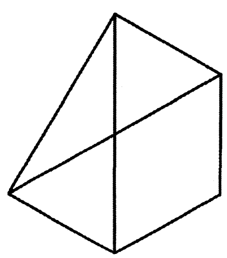


Is ROTATED To

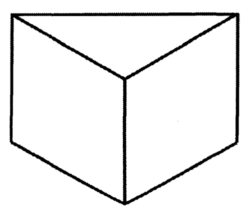
A



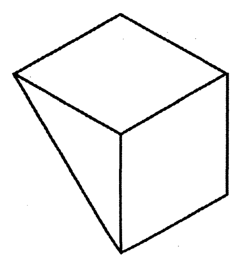
B



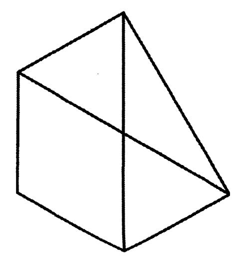
C



D



E



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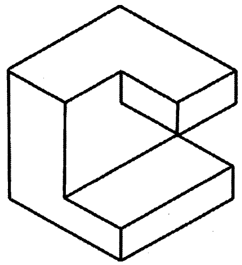
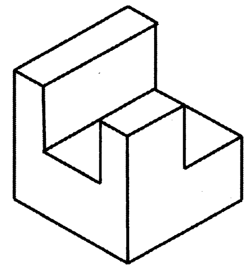
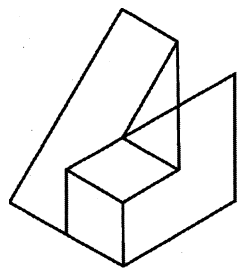


IS ROTATED TO

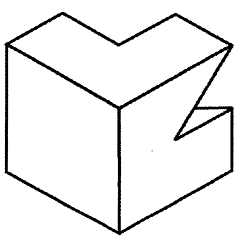


AS

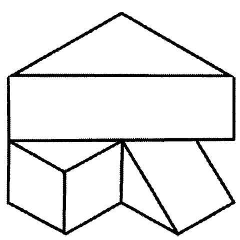


IS ROTATED TO

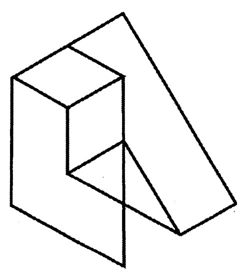
A



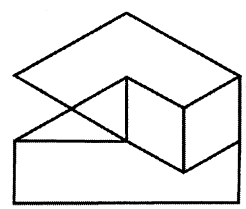
B



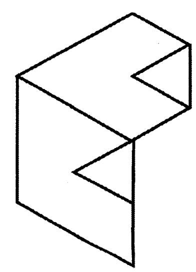
C



D



E



THANK YOU VERY MUCH!

Revised PSVT:R (2011)

Answer Key

1.	B	11.	E	21.	A
2.	A	12.	E	22.	D
3.	A	13.	B	23.	D
4.	D	14.	D	24.	C
5.	B	15.	C	25.	D
6.	C	16.	E	26.	C
7.	E	17.	A	27.	B
8.	E	18.	A	28.	E
9.	E	19.	B	29.	C
10.	D	20.	B	30.	E

Answer Sheet

ID:______________________________

1.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	11.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	21.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
2.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	12.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	22.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
3.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	13.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	23.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
4.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	14.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	24.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
5.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	15.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	25.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ

6.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	16.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	26.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
7.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	17.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	27.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
8.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	18.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	28.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
9.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	19.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	29.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
10.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	20.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	30.	Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ

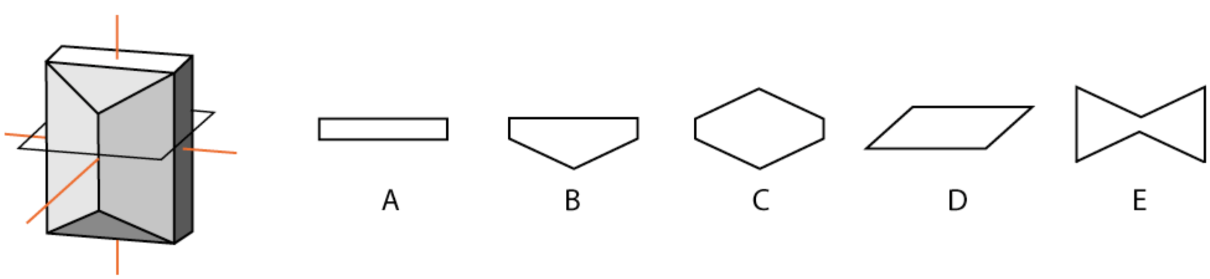
Crystallographic Slicing Test

UIN: ______________________________

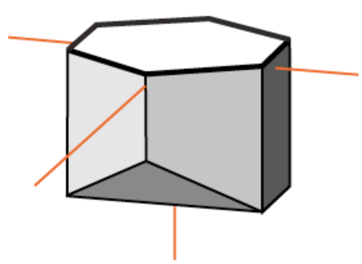
This portion of the survey tests your ability to visualize a slice through a three-dimensional solid. Each solid is the shape of an idealized, symmetrical mineral crystal, so it looks the same from the back as it does from the front.

Each problem consists of a diagram of a crystal intersected by a plane passing through the crystal. You are to determine the shape of the surface that would be made by cutting the crystal along the plane indicated (i.e., the intersection of the plane with the solid). Three mutually perpendicular (x, y, and z) axes are also shown on each diagram for reference, and in most cases they intersect at the center of the crystal. Shading indicates illumination from a light source at the upper left of each diagram.

Here's an example problem:

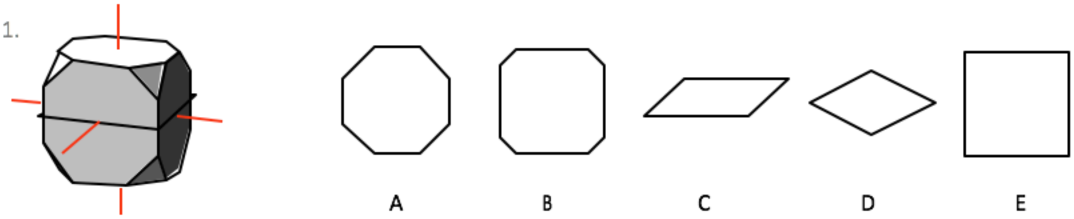


Answer "C" is correct because it shows the shape of intersection of the plane with this solid shape:



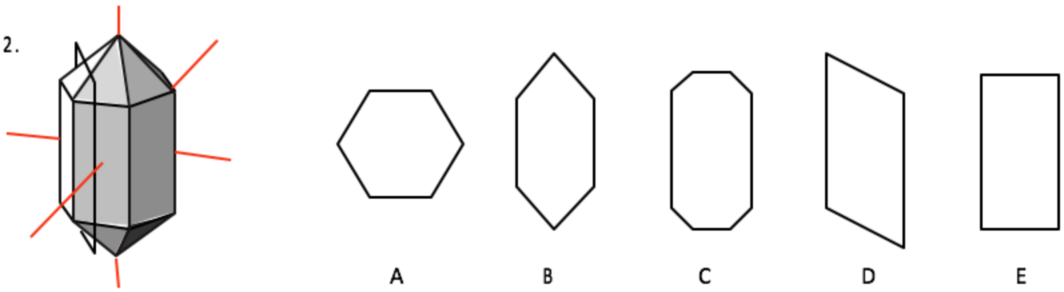
There are 15 questions in this part of the survey and you will have 3 minutes to work. Circle the best answer for each question.

1.



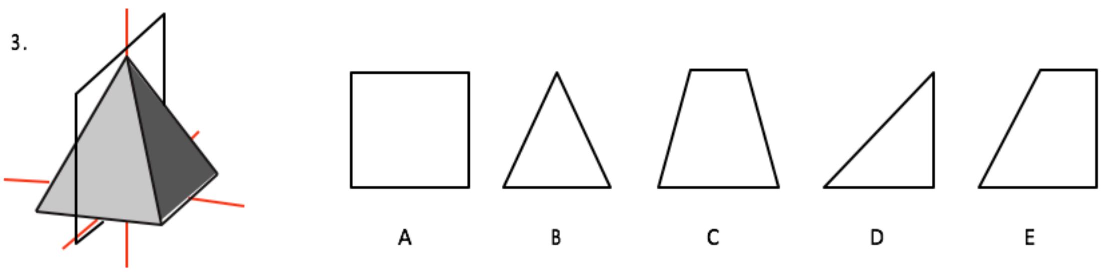
A B C D E

2.



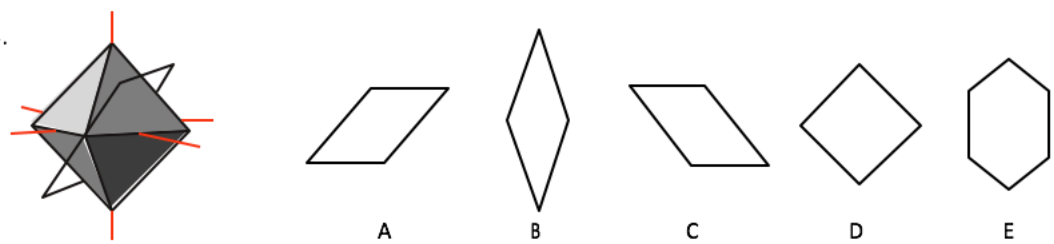
A B C D E

3.



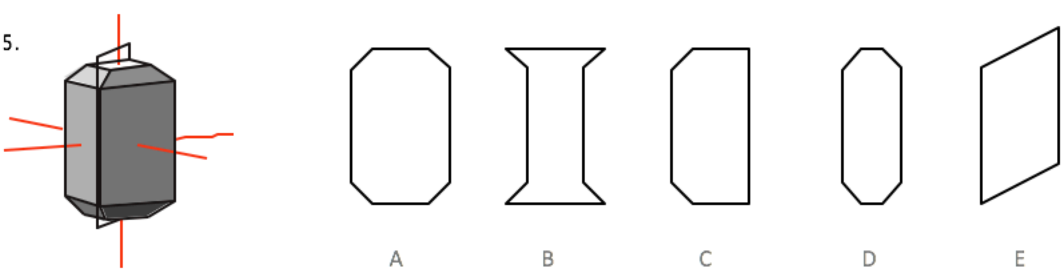
A B C D E

4.



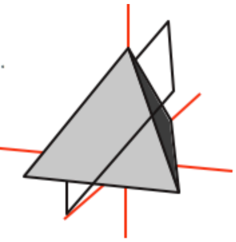
A B C D E

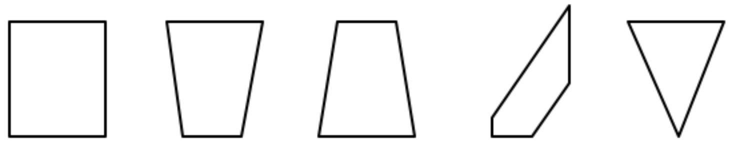
5.



A B C D E

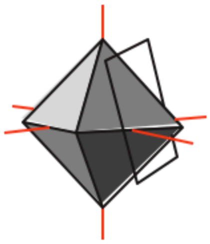
6.

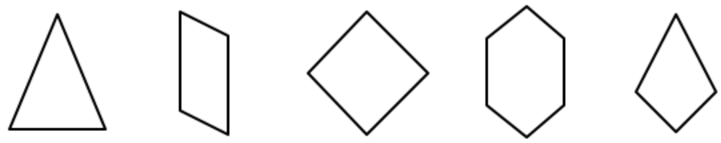




A B C D E

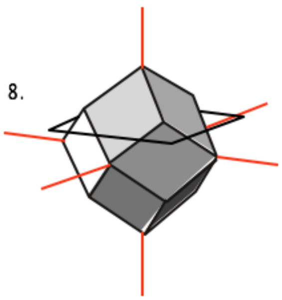
7.

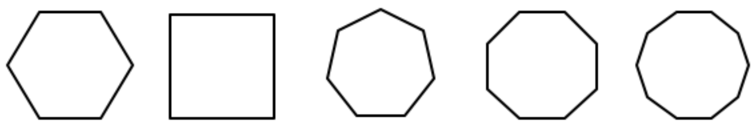




A B C D E

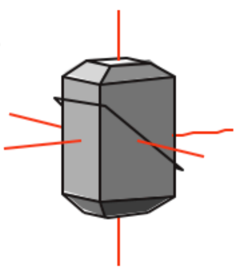
8.

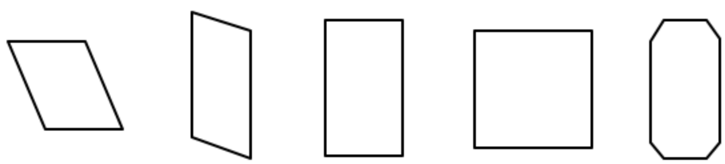




A B C D E

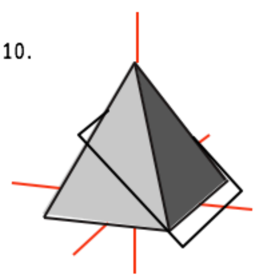
9.

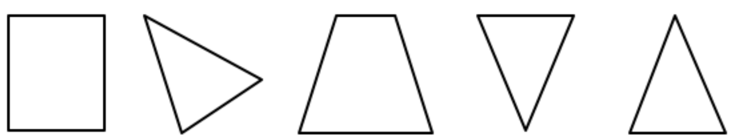




A B C D E

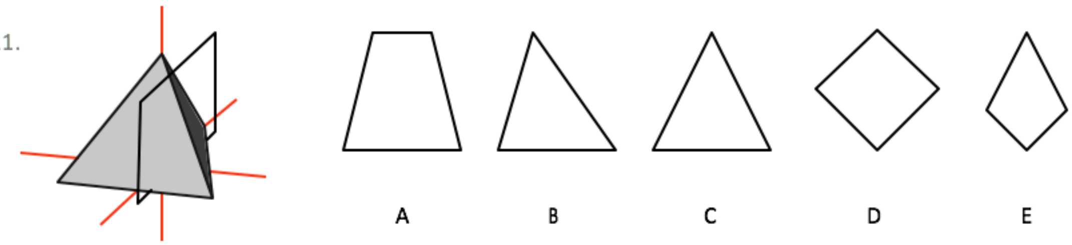
10.





A B C D E

11.



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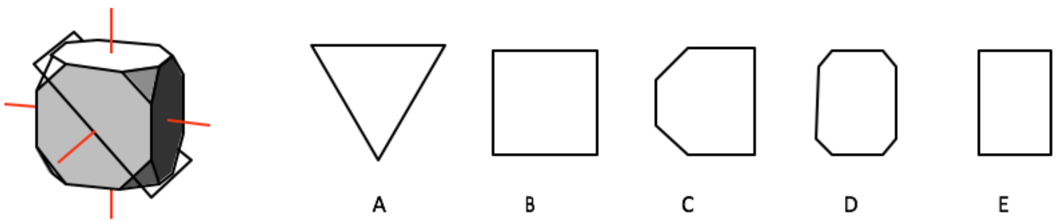

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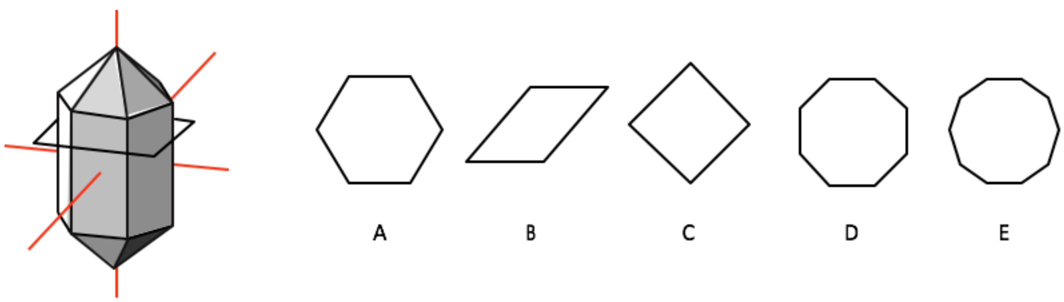
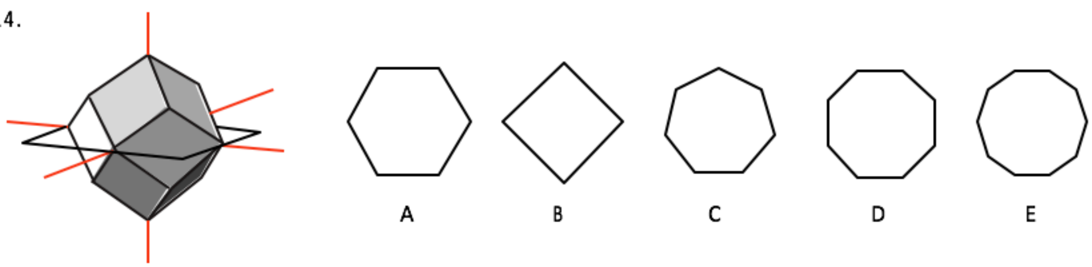
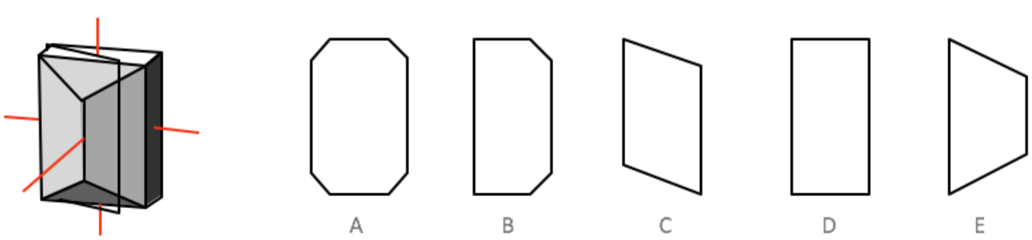


14.



15.



UIN______________________

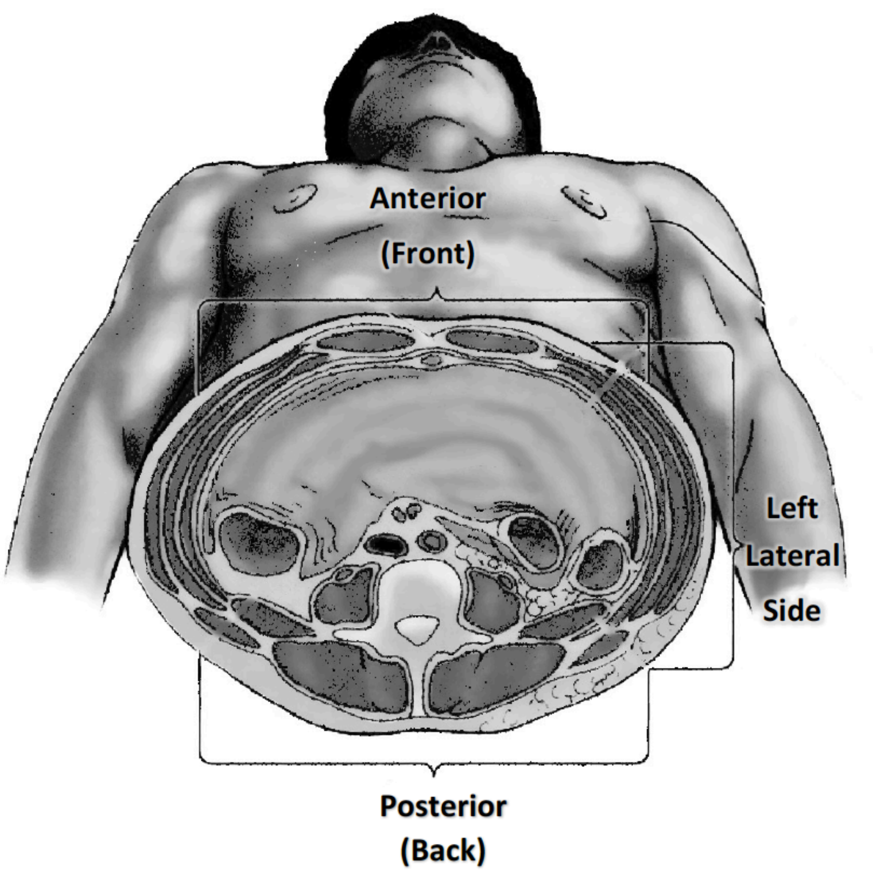
Anatomic Spatial Reasoning Assessment

(Level 1)

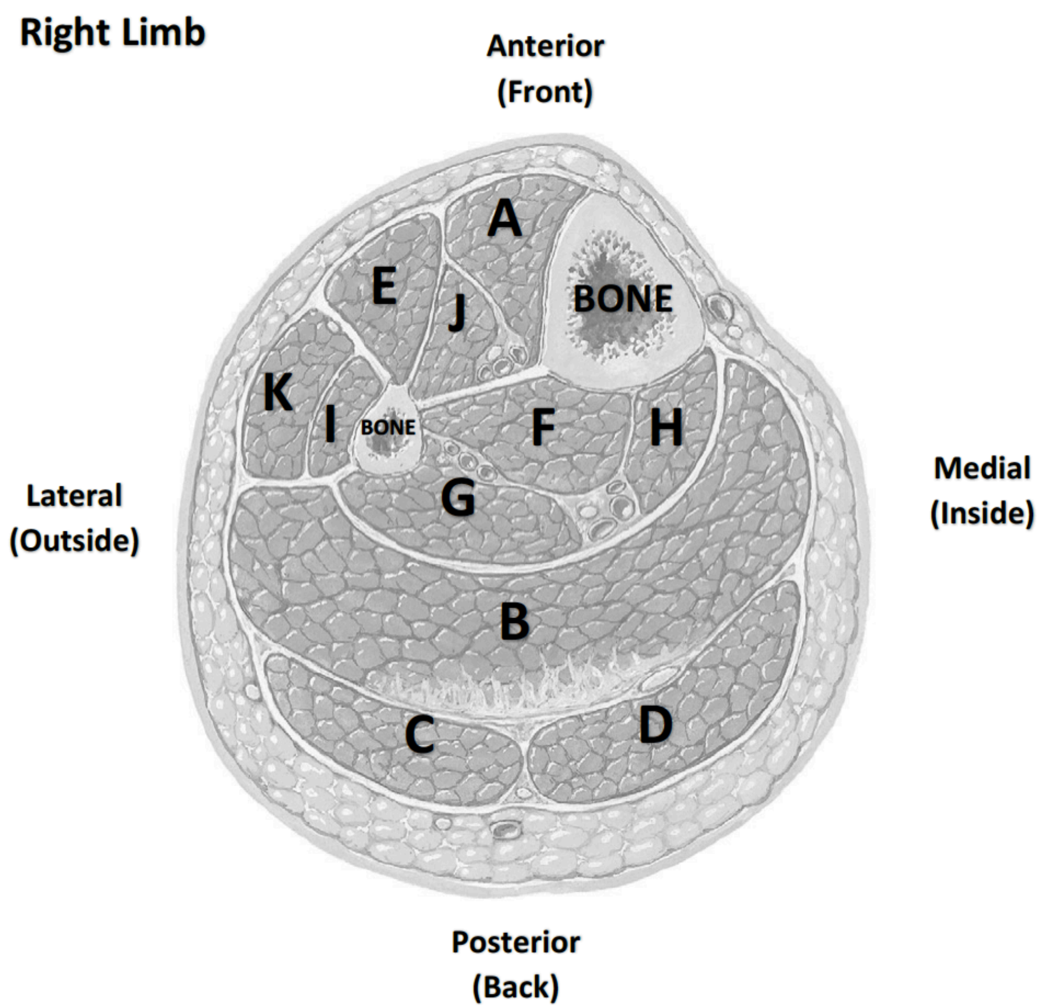
The following questions are designed to assess your ability to create mental models and then assess the relationships amongst anatomical structures using these models. You will have 15 minutes to complete all 25 questions.

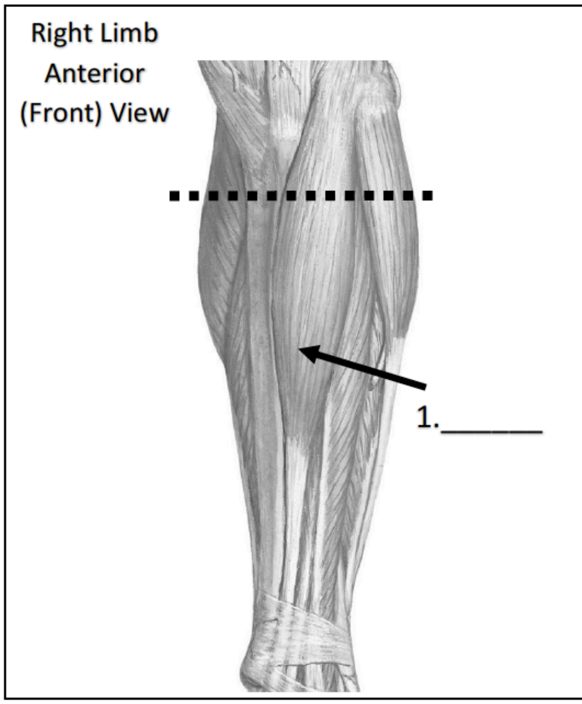
For each question, use the given cross-section diagram labeled with letters to identify which muscle the arrow is pointing to in the given image. Some muscles are identified for you as reference. The dotted line on the images represents the level at which the cross-section was taken. (Images are from Netter's Atlas of Human Anatomy, 6th edition and Miller's Anatomy of the Dog, 4th edition.)

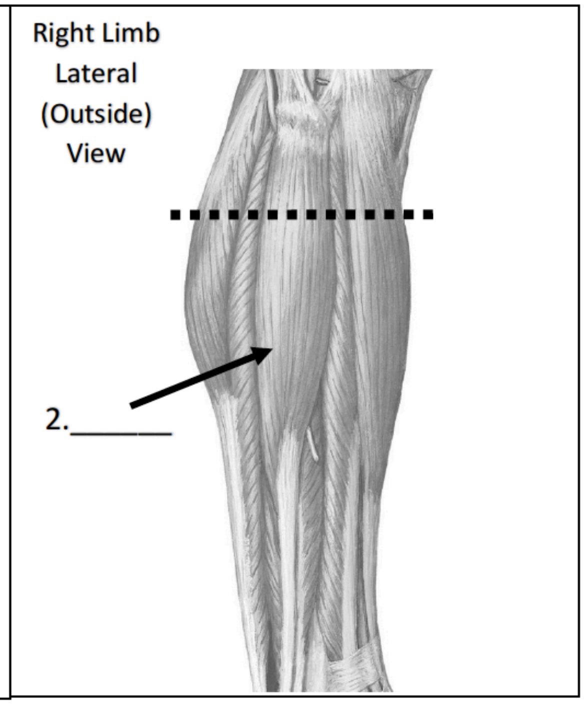
Cross sections are oriented as illustrated in this image:

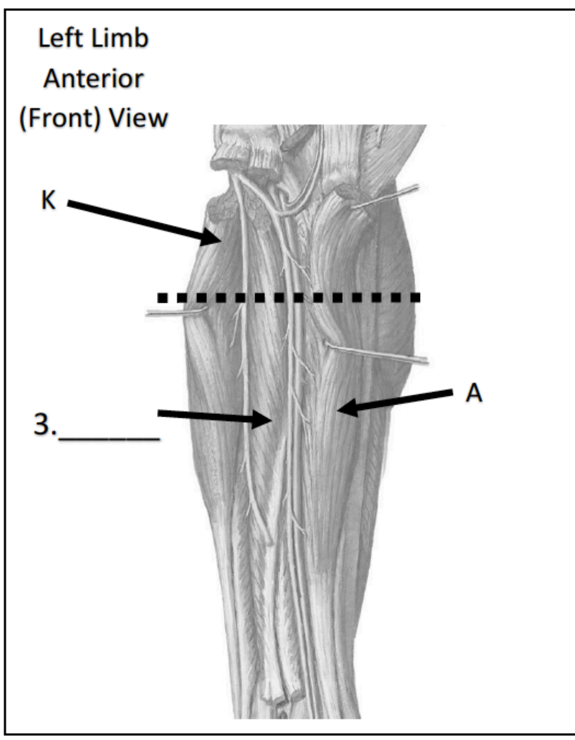


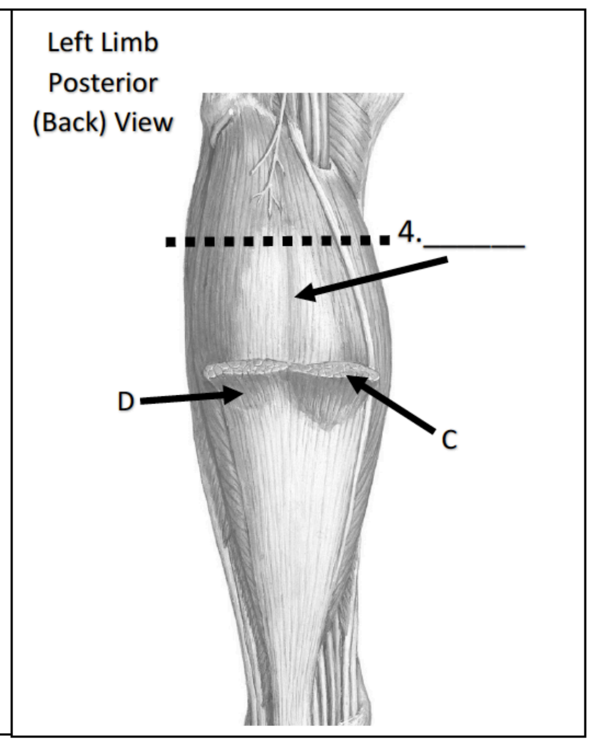
Use the following as an example:









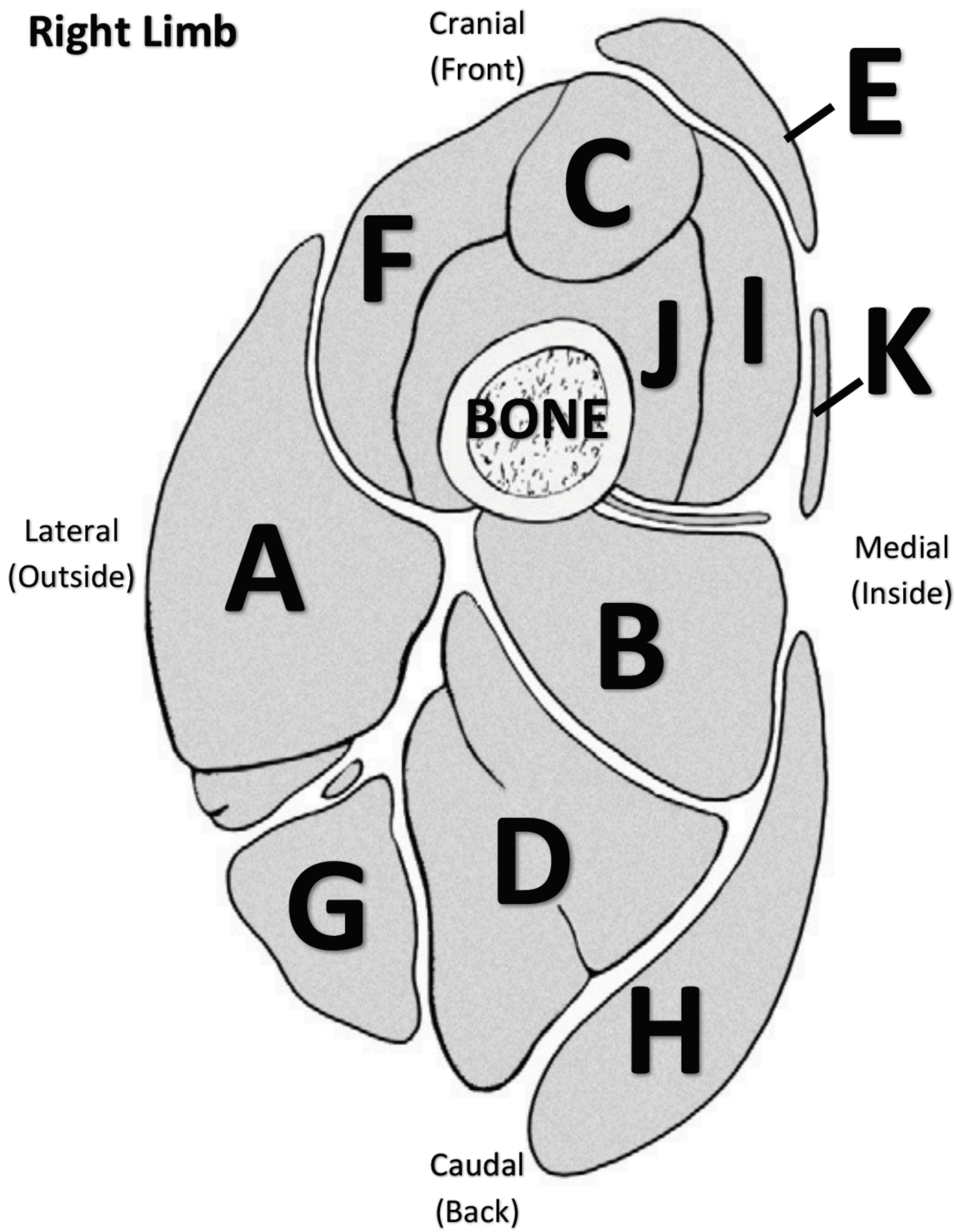


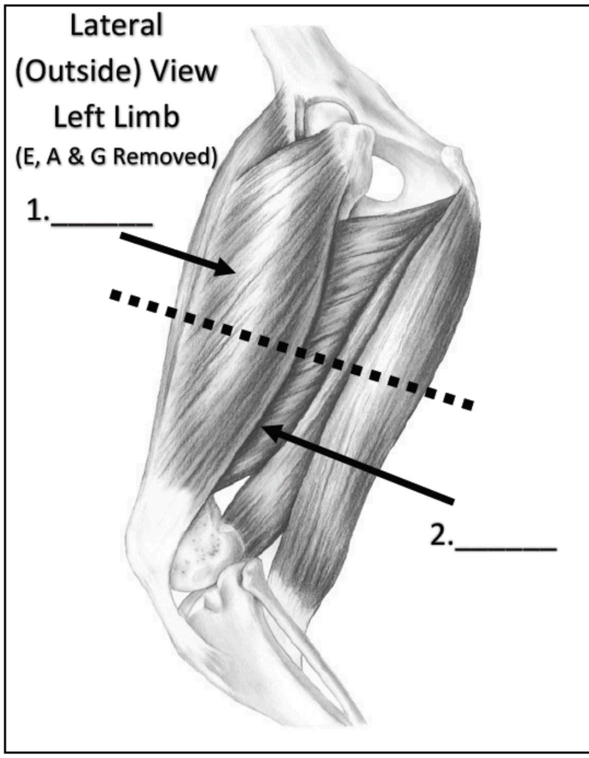
Answers:

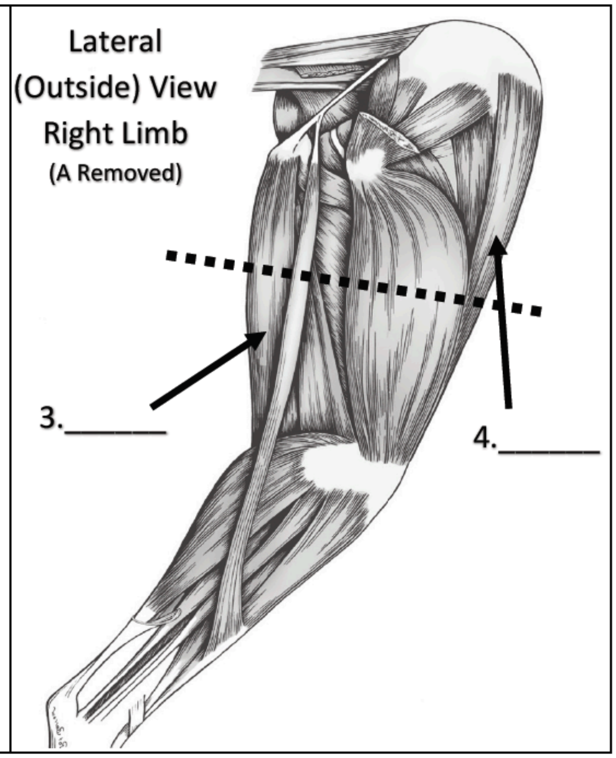
1. A   2. K   3. E   4. B

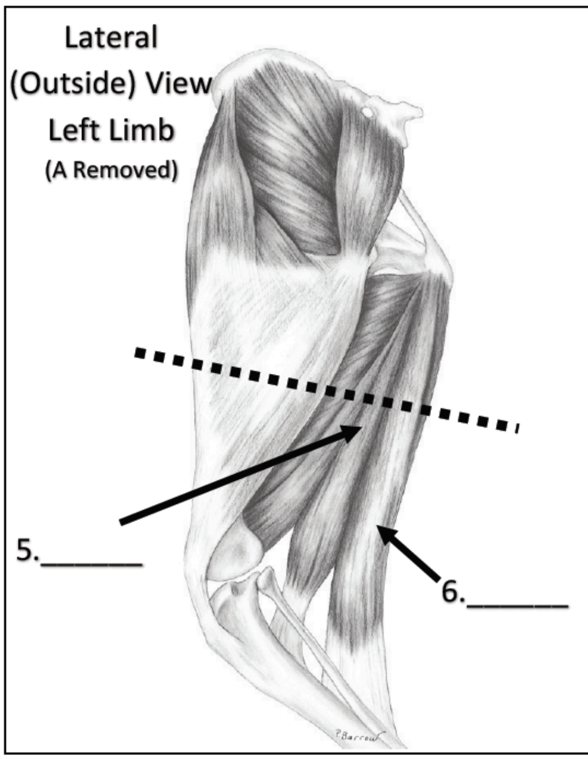
STOP!

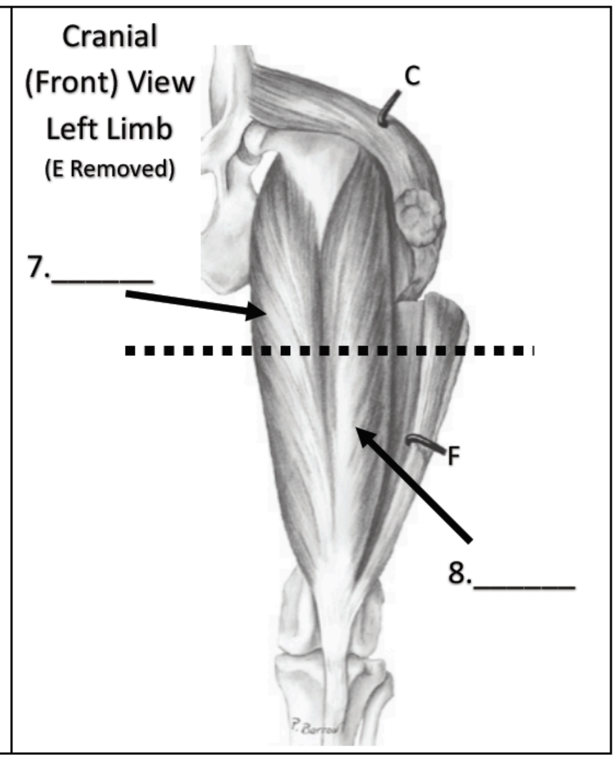
THE NEXT PAGE BEGINS THE ASSESSMENT

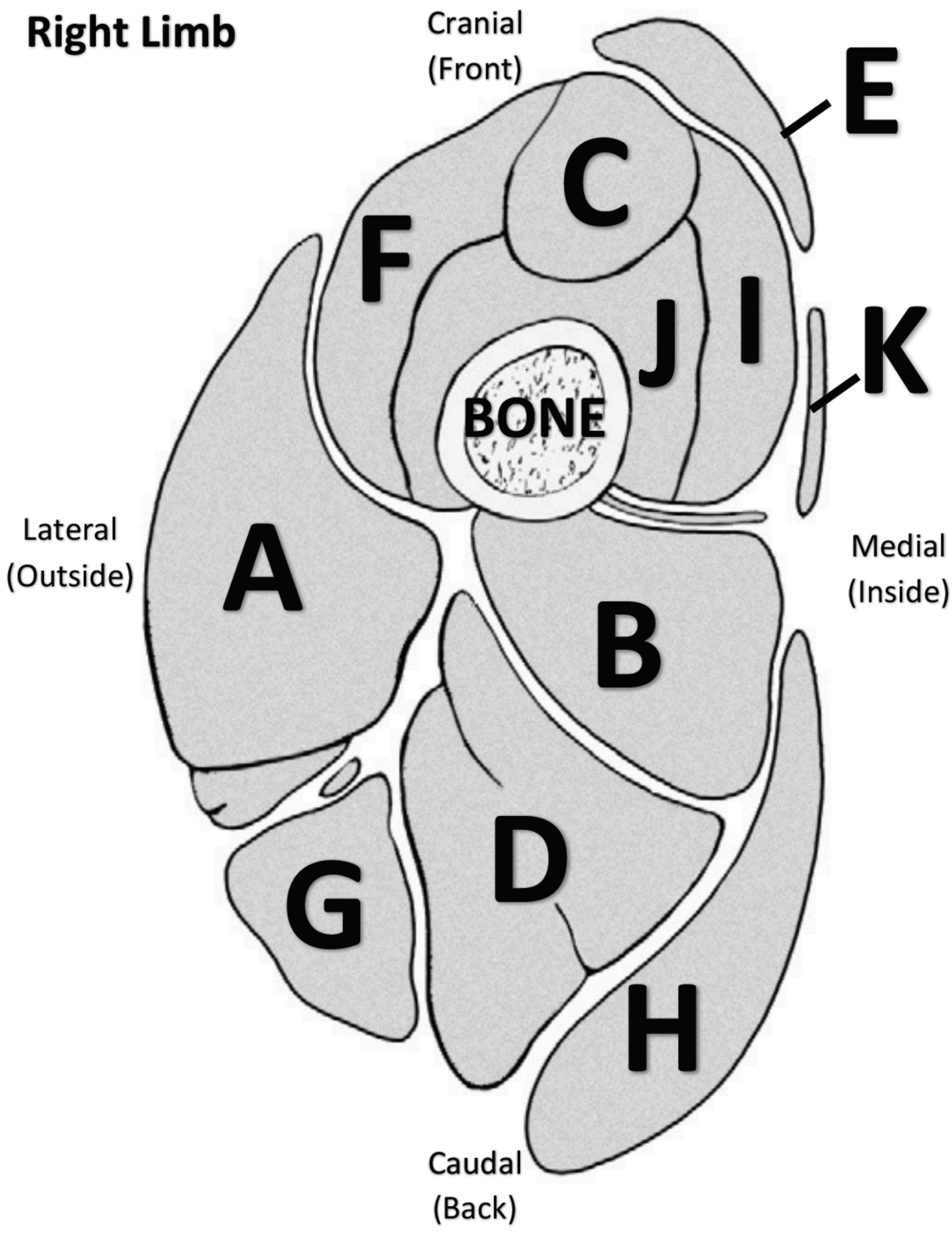

Right Limb
Cranial
(Front)
E
C
F
J
I
K
BONE
Lateral
(Outside)
A
Medial
(Inside)
B
D
G
H
Caudal
(Back)

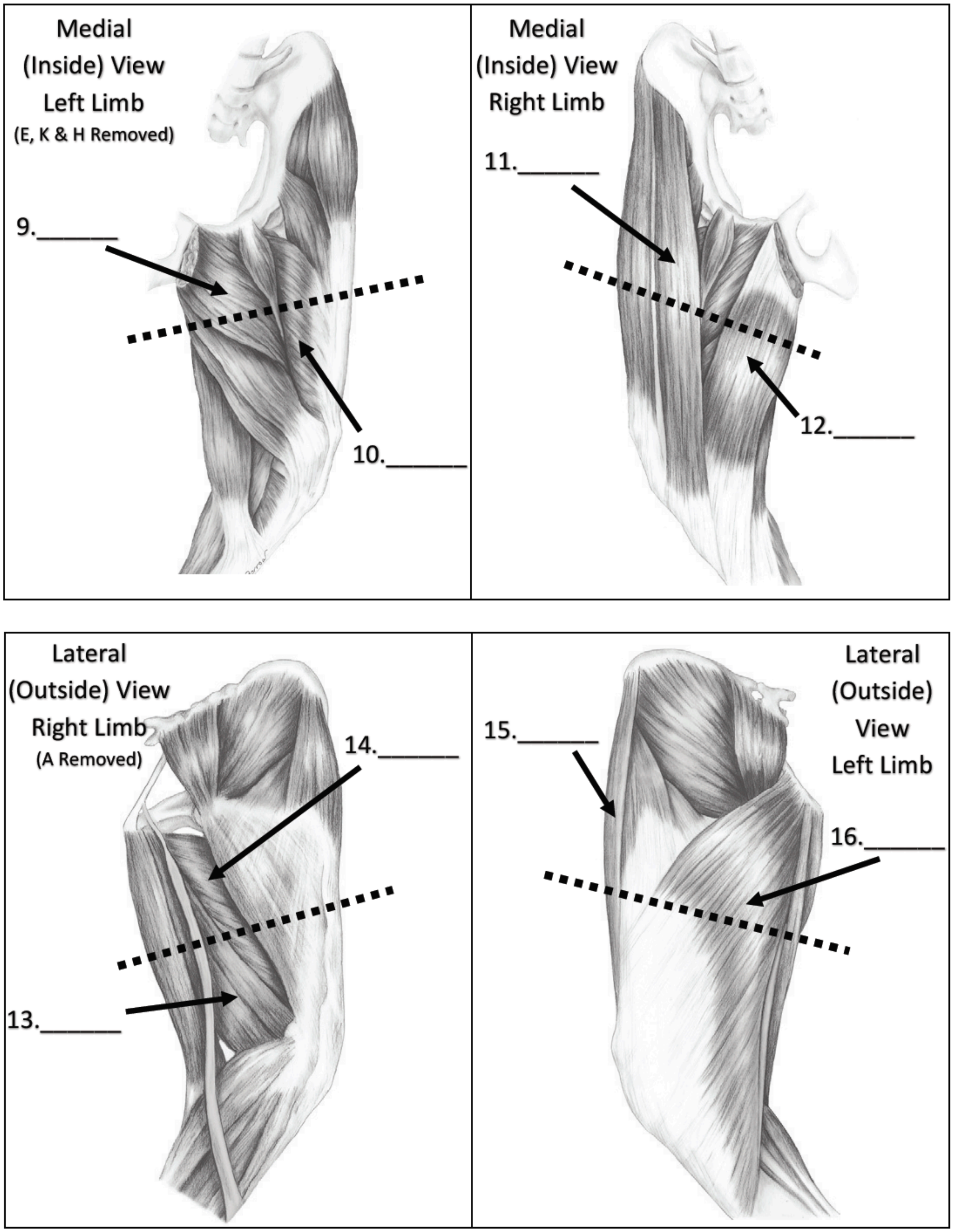

Lateral
(Outside) View
Left Limb
(E, A & G Removed)
1.______
2.______

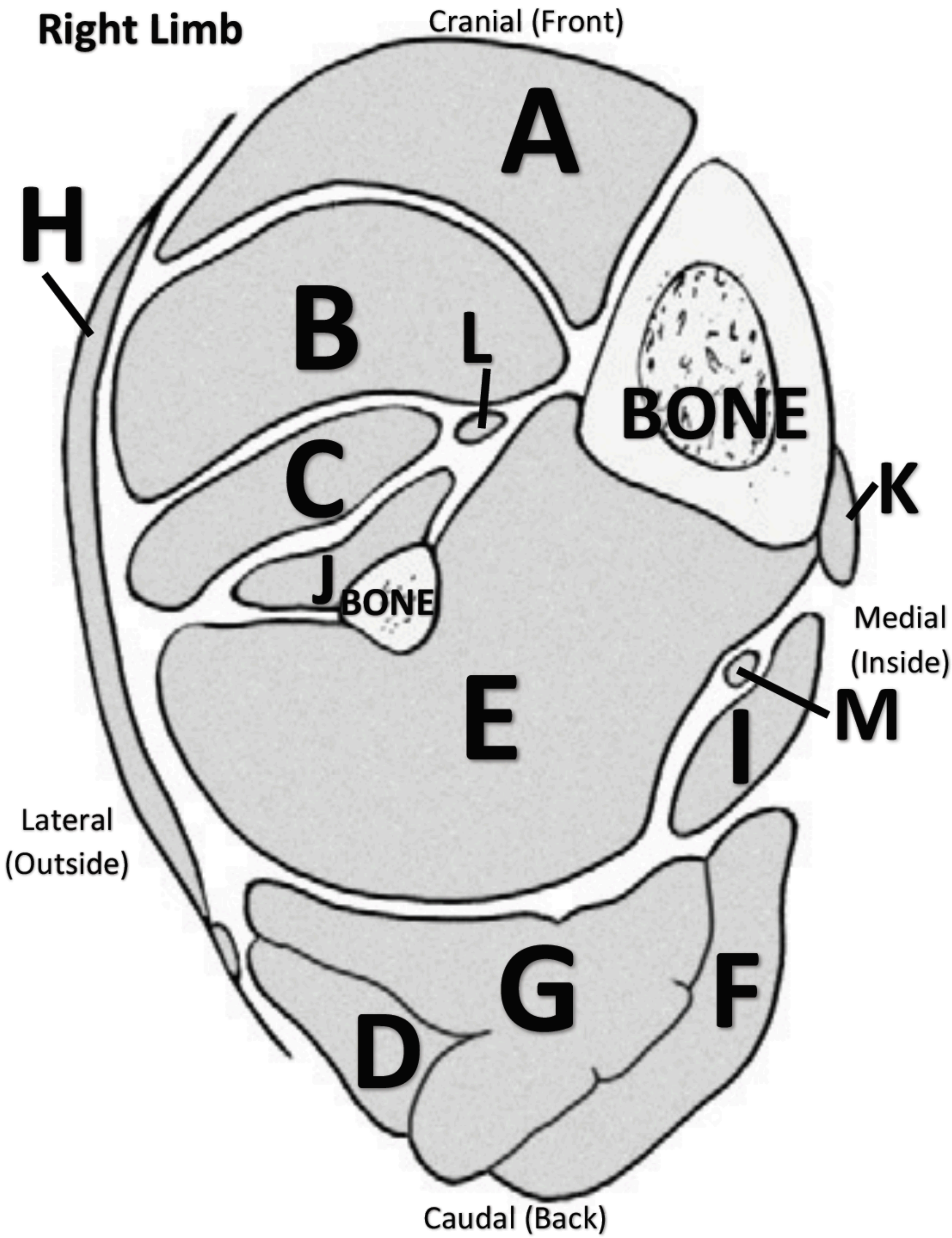

Lateral
(Outside) View
Right Limb
(A Removed)
3.______
4.______


Lateral
(Outside) View
Left Limb
(A Removed)
5.______
6.______

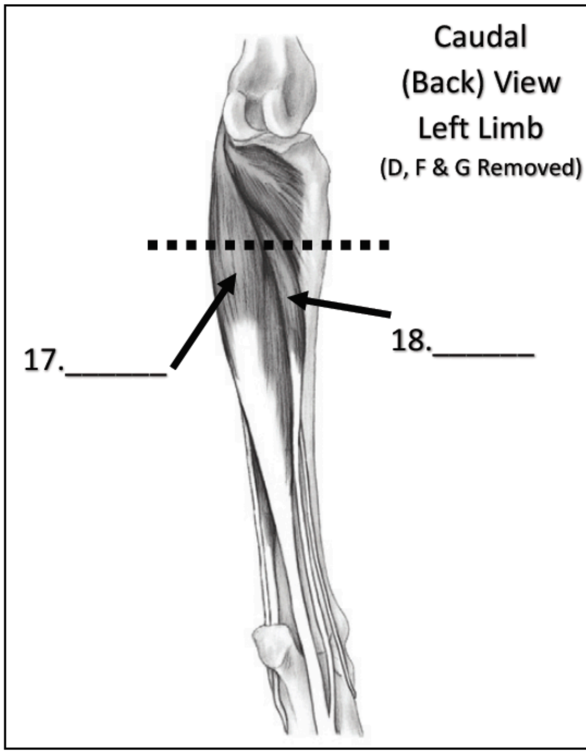

Cranial
(Front) View
Left Limb
(E Removed)
C
7.______
F
8.______

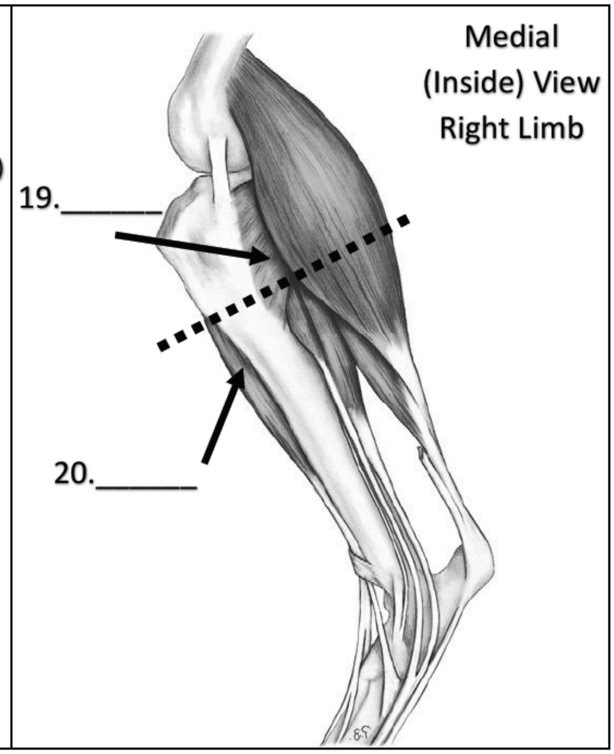

Right Limb
Cranial
(Front)
E
C
F
J
I
K
BONE
Lateral
(Outside)
A
Medial
(Inside)
B
D
G
H
Caudal
(Back)

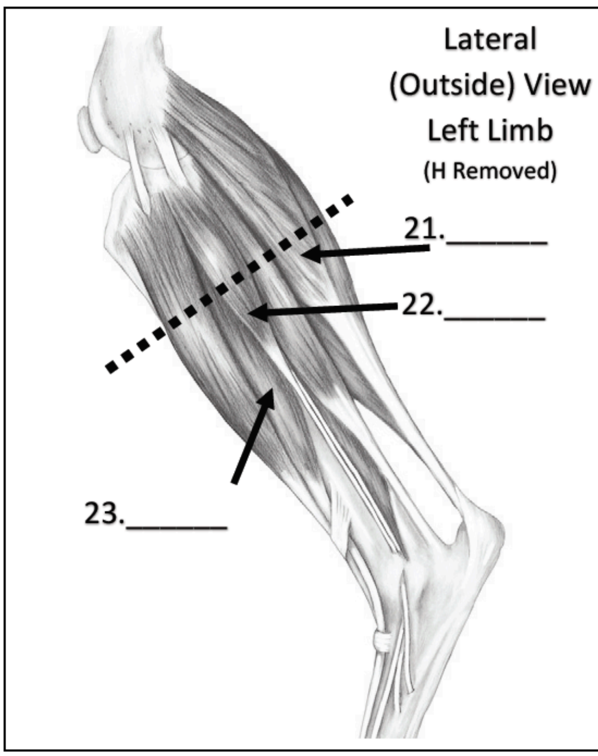

Medial
(Inside) View
Left Limb
(E, K & H Removed)
9.______
10.______
Medial
(Inside) View
Right Limb
11.______
12.______
Lateral
(Outside) View
Right Limb
(A Removed)
14.______
13.______
Lateral
(Outside)
View
Left Limb
15.______
16.______

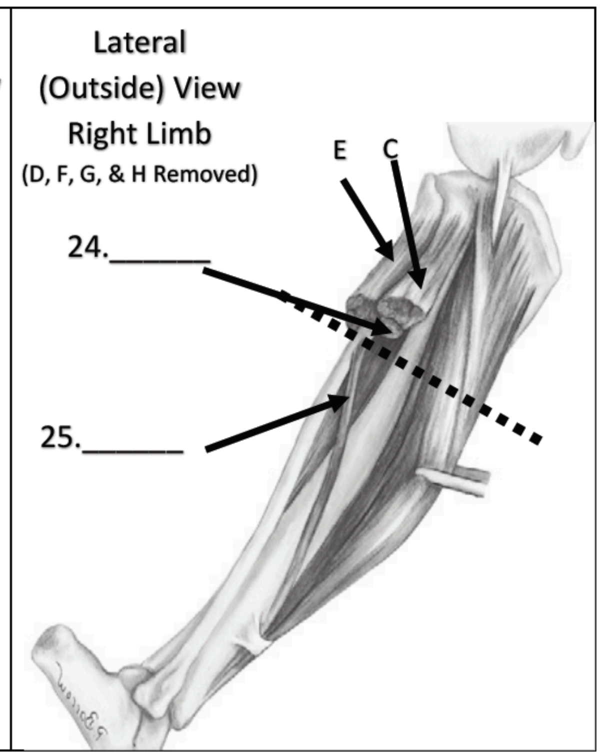


Right Limb
Cranial (Front)
A
H
B
L
BONE
C
K
J
BONE
Medial
(Inside)
M
E
I
Lateral
(Outside)
G
F
D
Caudal (Back)


Caudal
(Back) View
Left Limb
(D, F & G Removed)
17.______
18.______


Medial
(Inside) View
Right Limb
19.______
20.______


Lateral
(Outside) View
Left Limb
(H Removed)
21.______
22.______
23.______


Lateral
(Outside) View
Right Limb
(D, F, G, & H Removed)
E
C
24.______
25.______

UIN:________________________

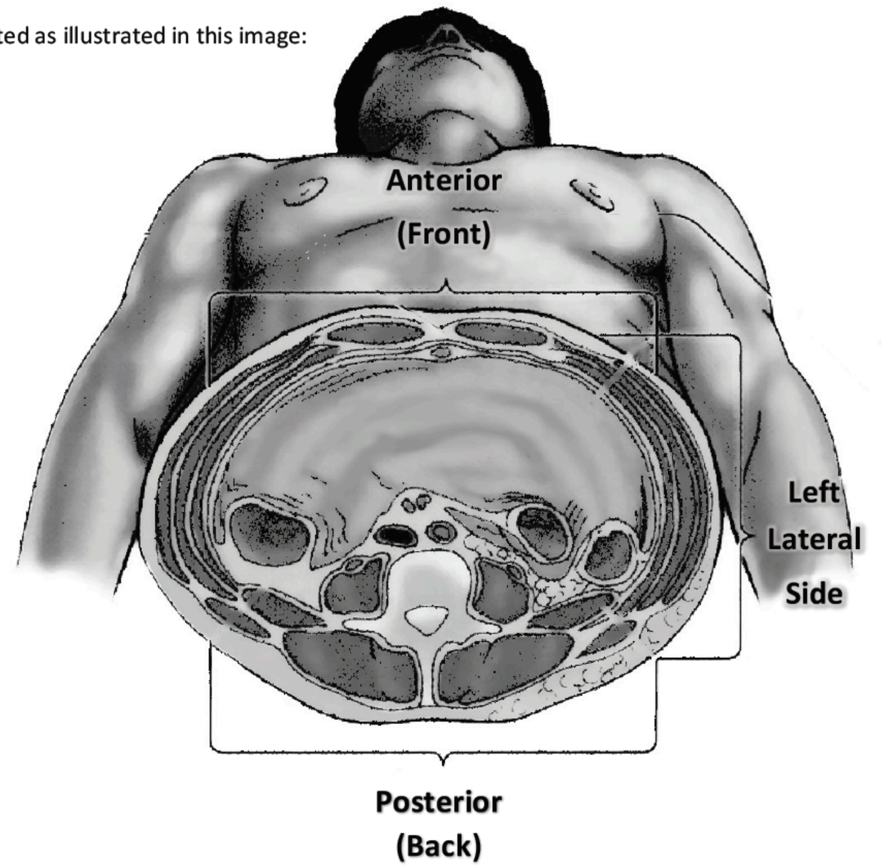
Anatomic Spatial Reasoning Assessment

(Level 2)

The following questions are designed to assess your ability to create mental models and then assess the relationships amongst anatomical structures using these models. You will have 15 minutes to complete all 25 questions.

For each question, use the given cross-section diagram labeled with letters to identify which muscle the arrow is pointing to in the given image. Some muscles are identified for you as reference. The dotted line on the images represents the level at which the cross-section was taken. (Images are from Netter's Atlas of Human Anatomy, 6th edition)

Cross sections are oriented as illustrated in this image:



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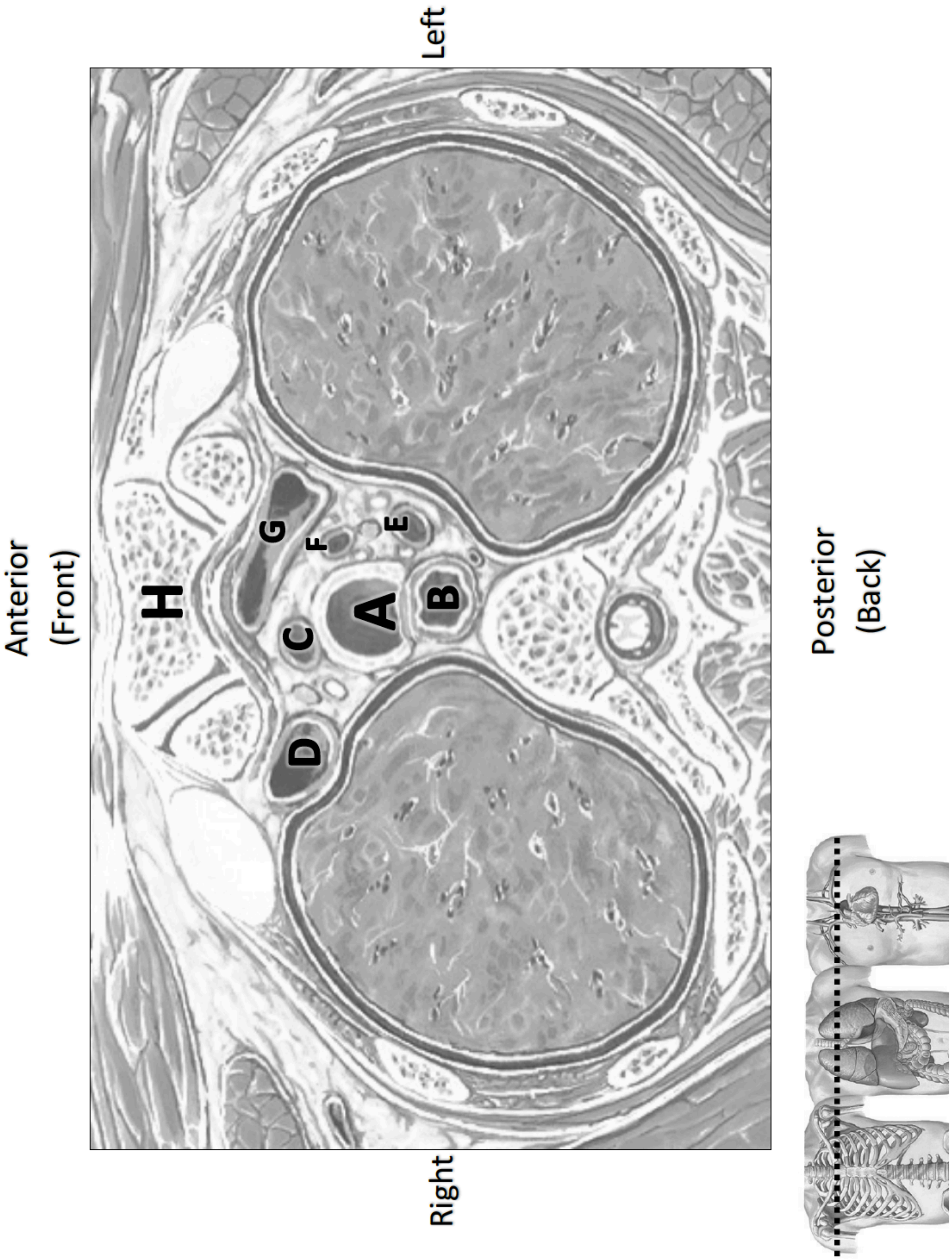
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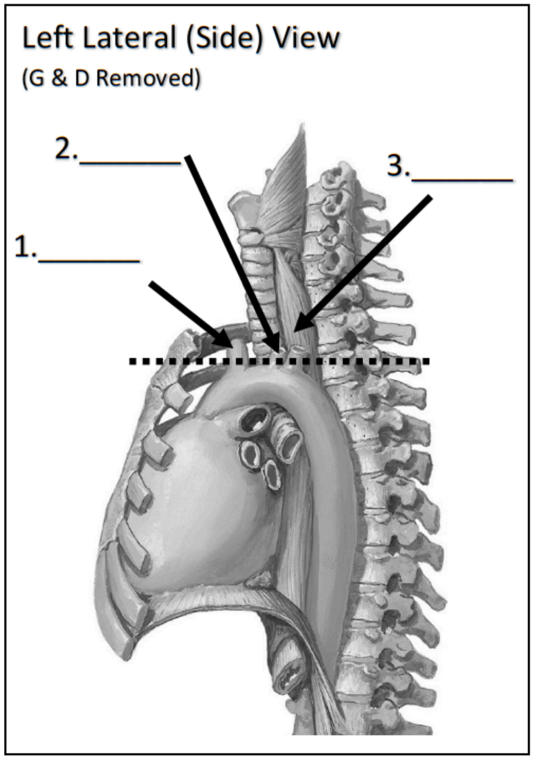
Left Lateral (Side) View
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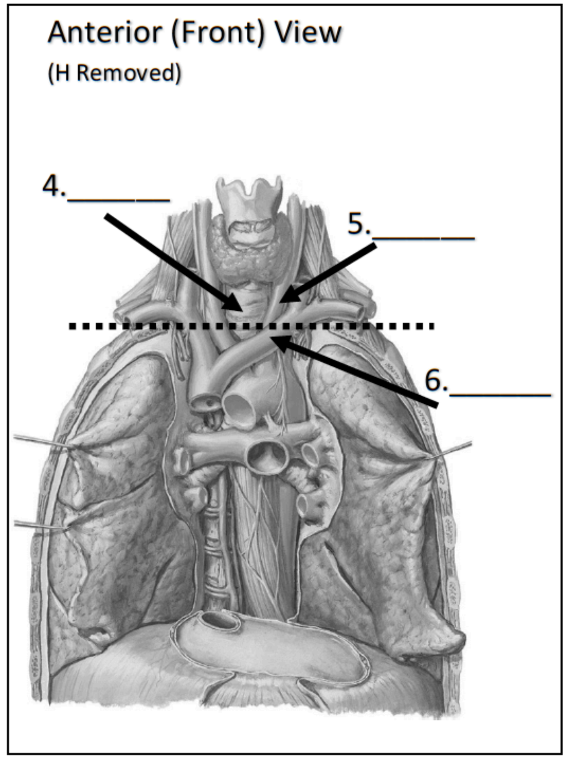
Anterior (Front) View
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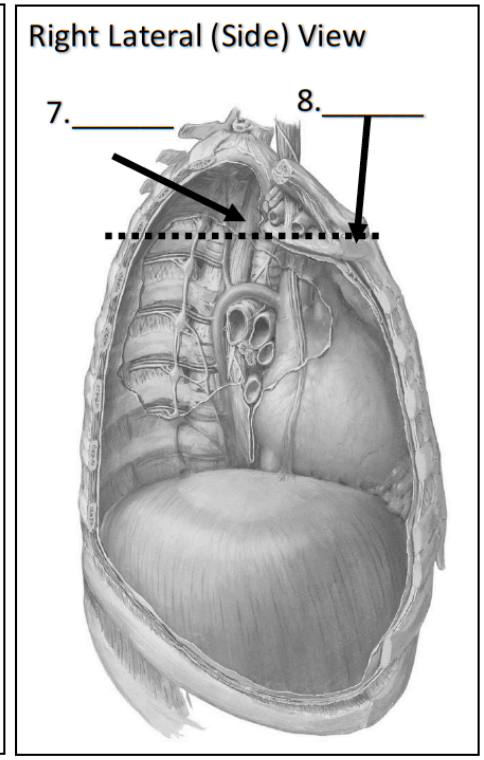
Right Lateral (Side) View
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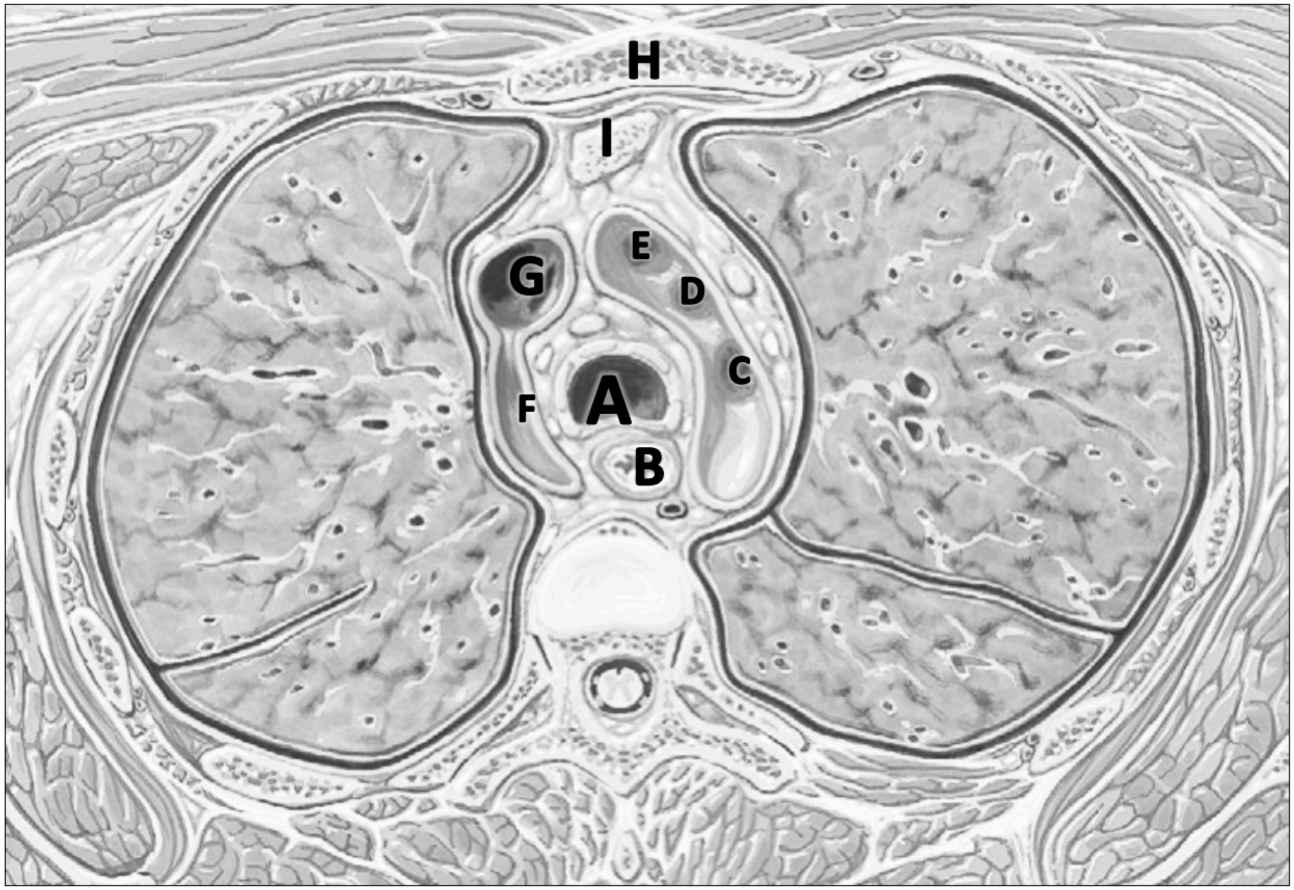
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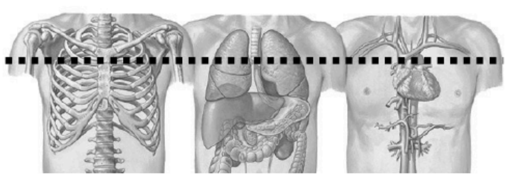

Anterior (Front) View
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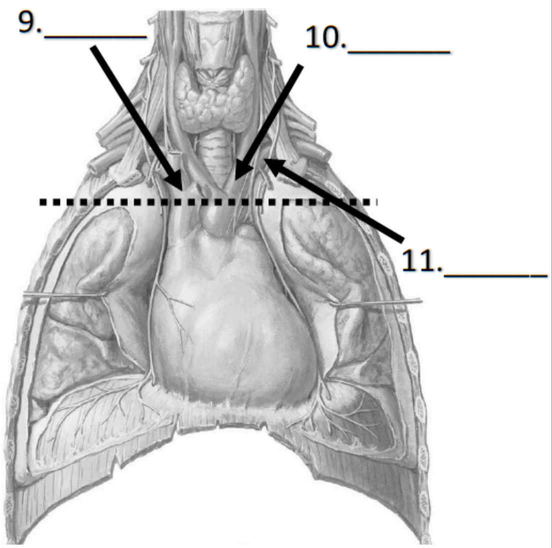
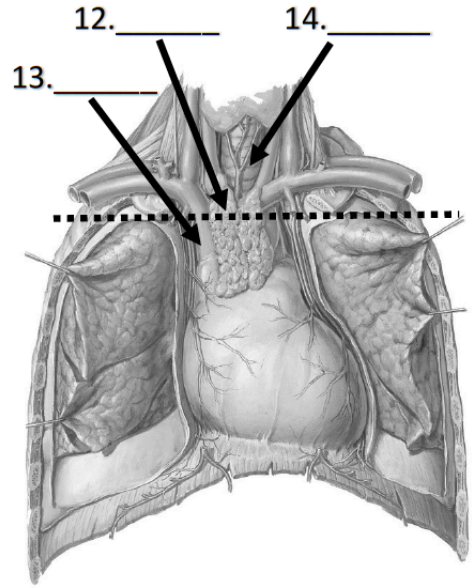
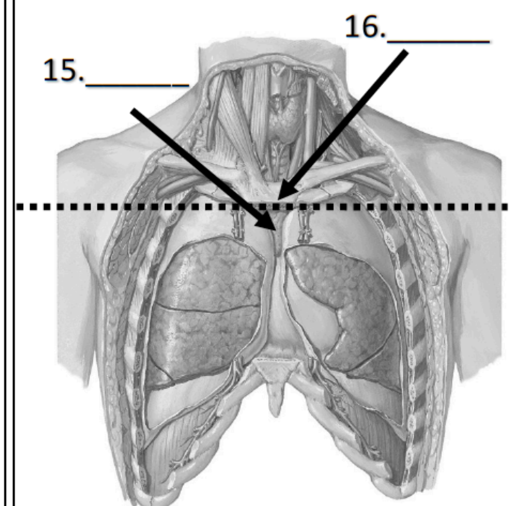
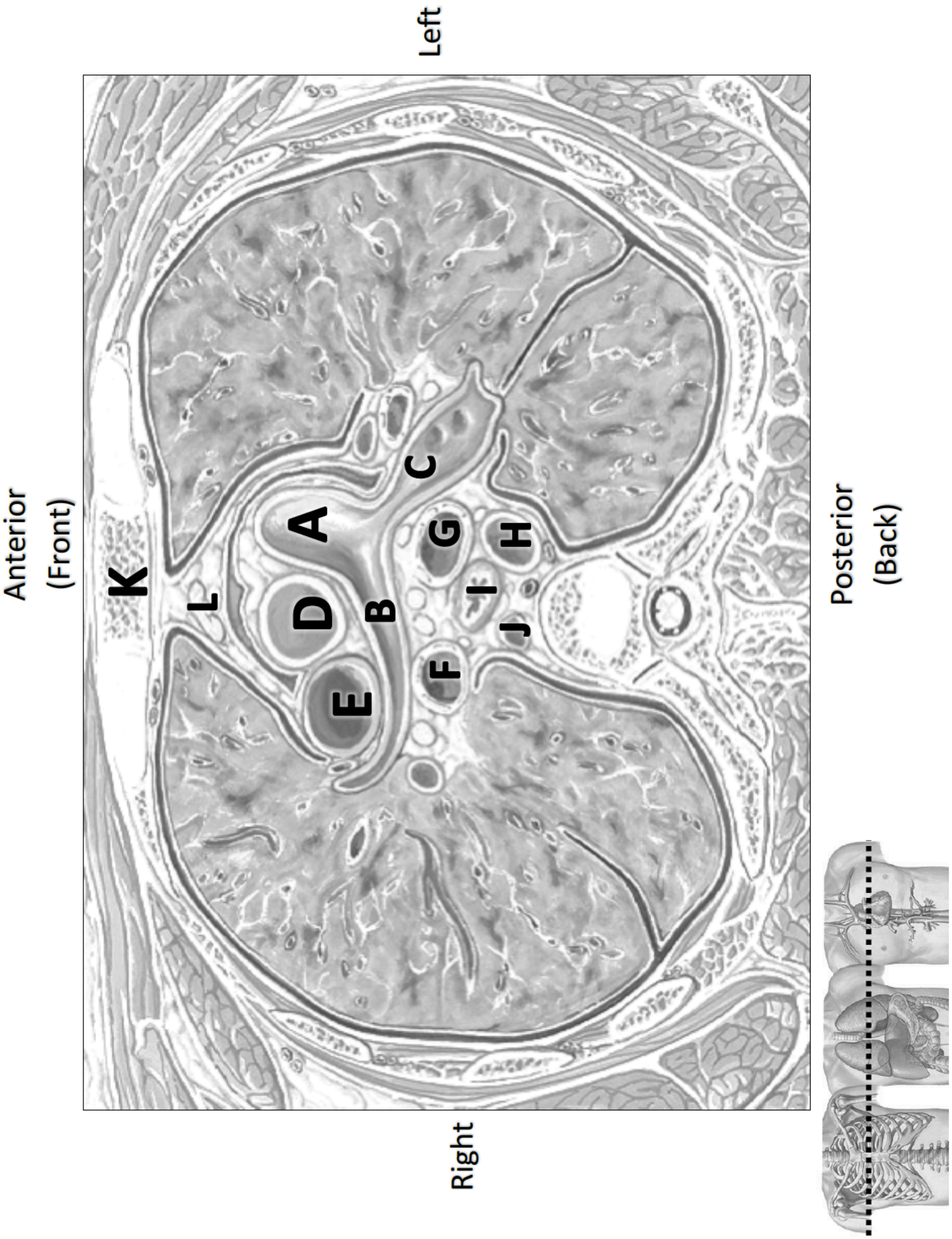


Anterior (Front) View
(H Removed)



Anterior (Front) View

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Anterior (Front) View
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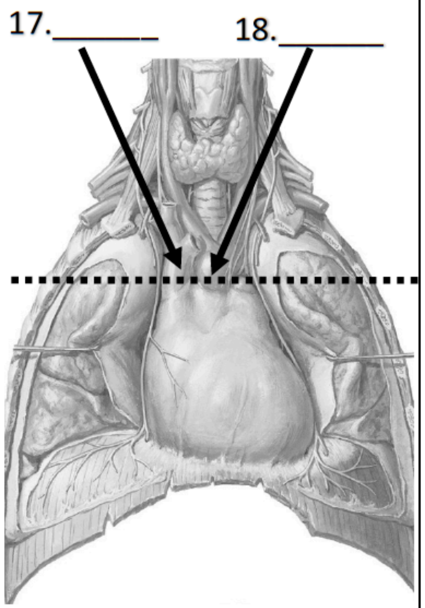
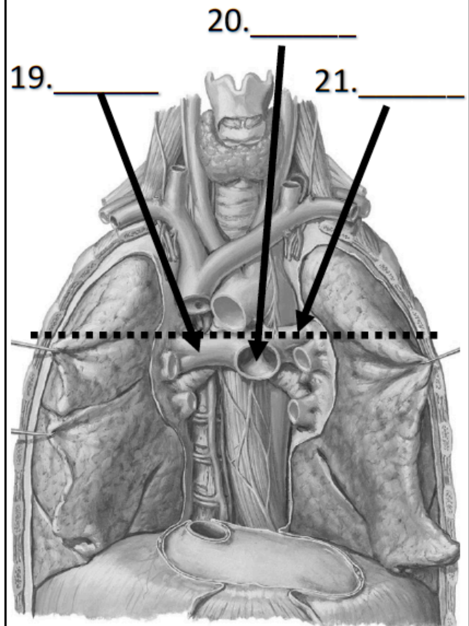
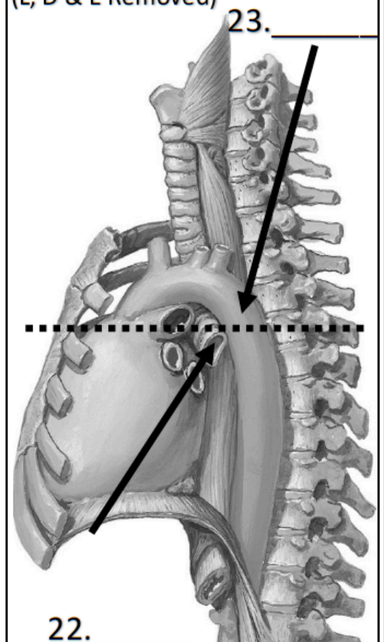


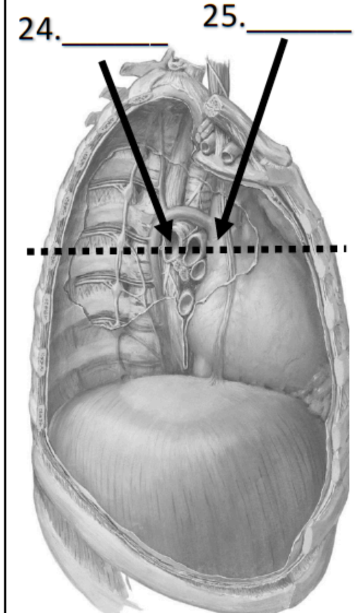
Anterior (Front) View
(K, L, D, & E Removed)



Left Lateral (Side) View
(L, D & E Removed)



Right Lateral (Side)View



UIN: ______________________

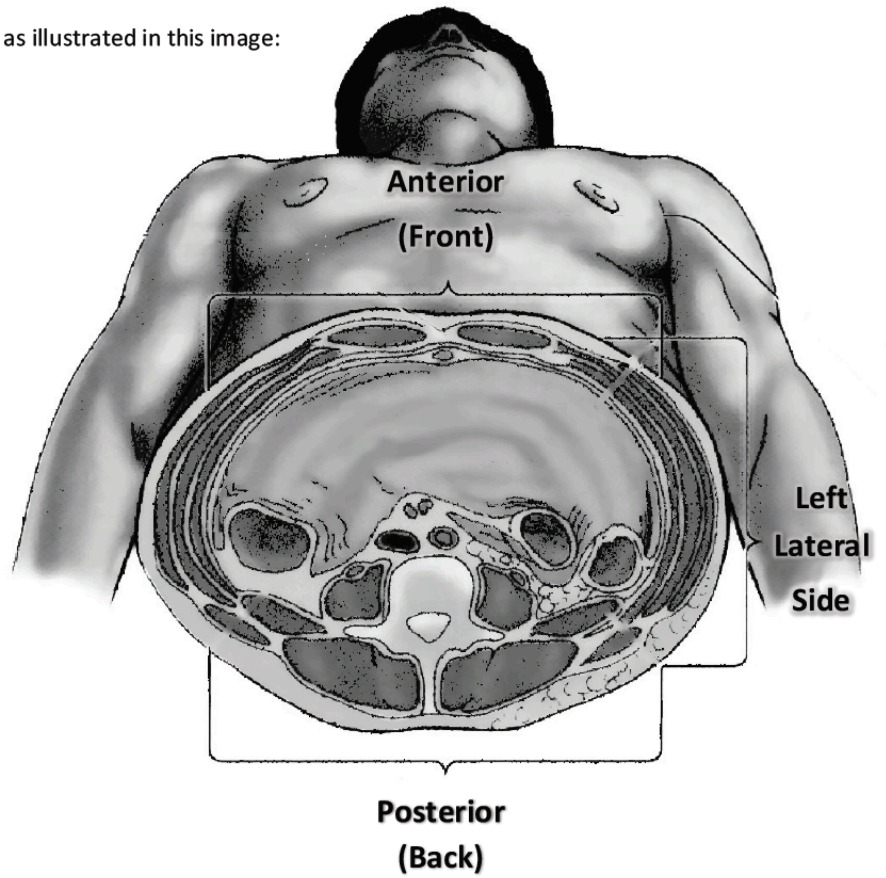
Anatomic Spatial Reasoning Assessment

(Level 3)

The following questions are designed to assess your ability to create mental models and then assess the relationships amongst anatomical structures using these models. You will have 15 minutes to complete all 25 questions.

For each question, use the given cross-section diagram labeled with letters to identify which muscle the arrow is pointing to in the given image. Some muscles are identified for you as reference. The dotted line on the images represents the level at which the cross-section was taken. (Images are from Netter's Atlas of Human Anatomy, 6th edition)

Cross sections are oriented as illustrated in this image:



STOP!

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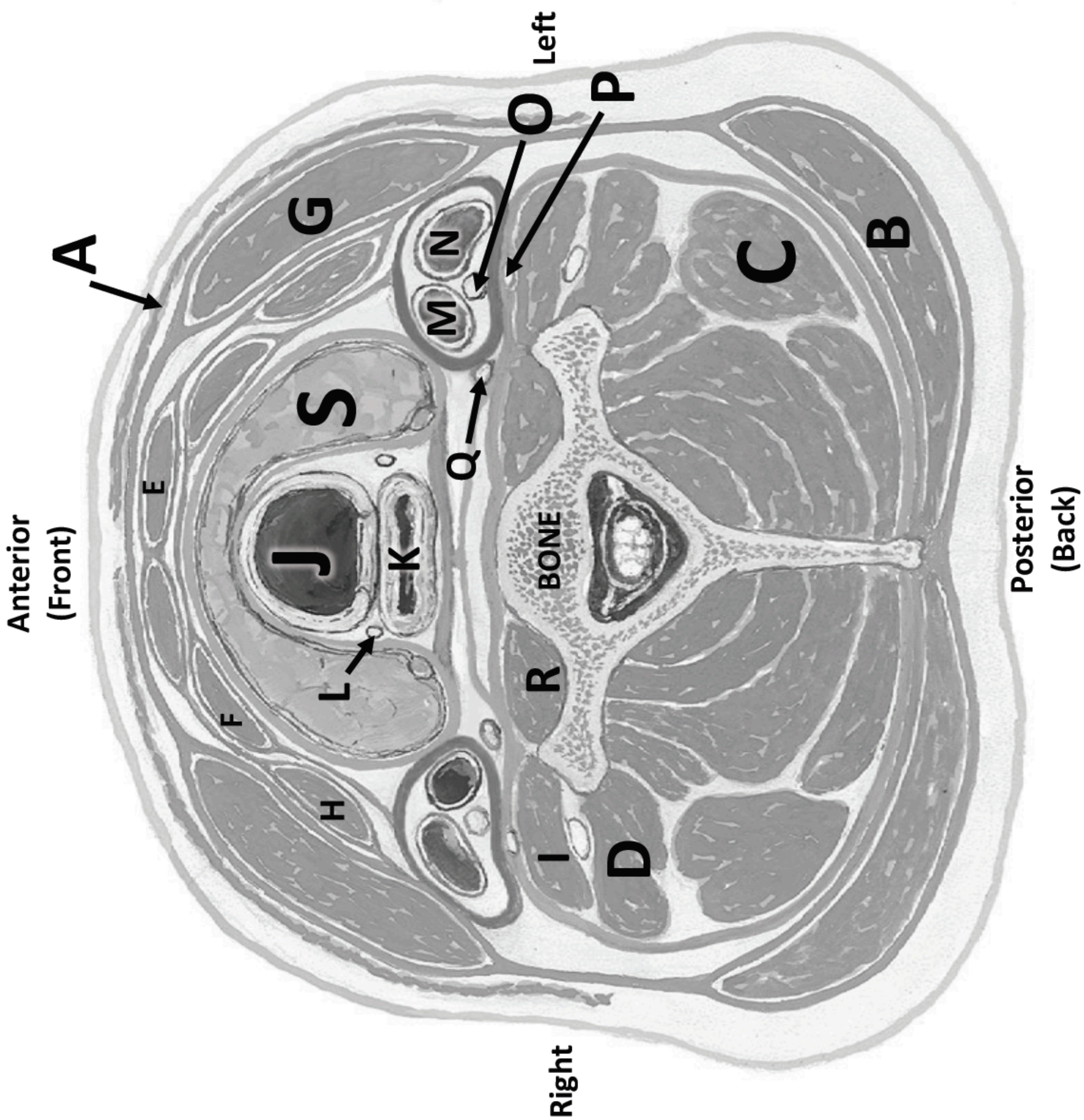

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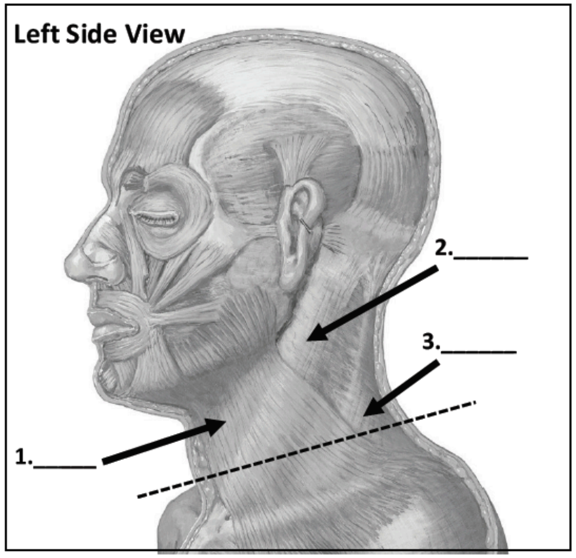
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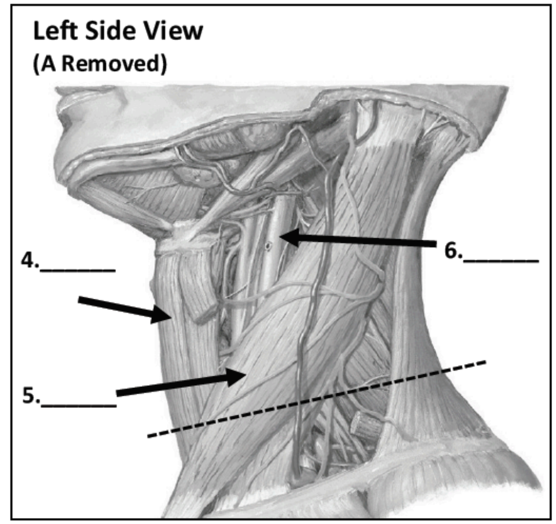
Left Side View
(A Removed)
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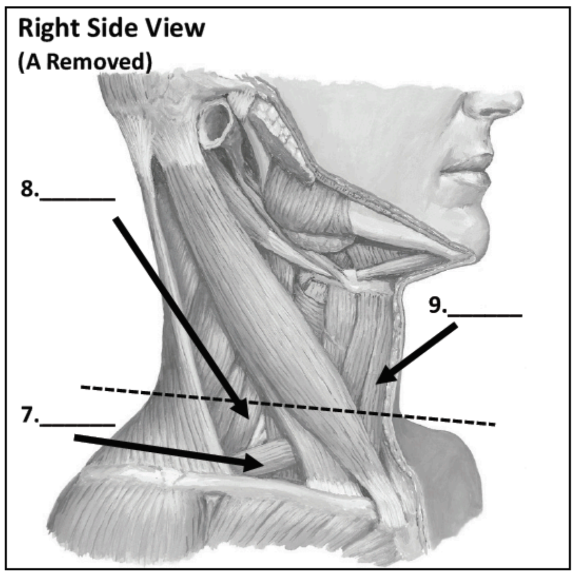
Right Side View
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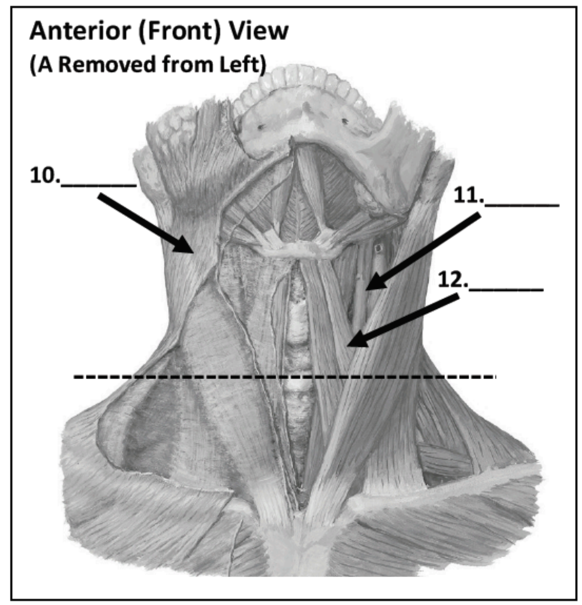
Anterior (Front) View
(A Removed from Left)
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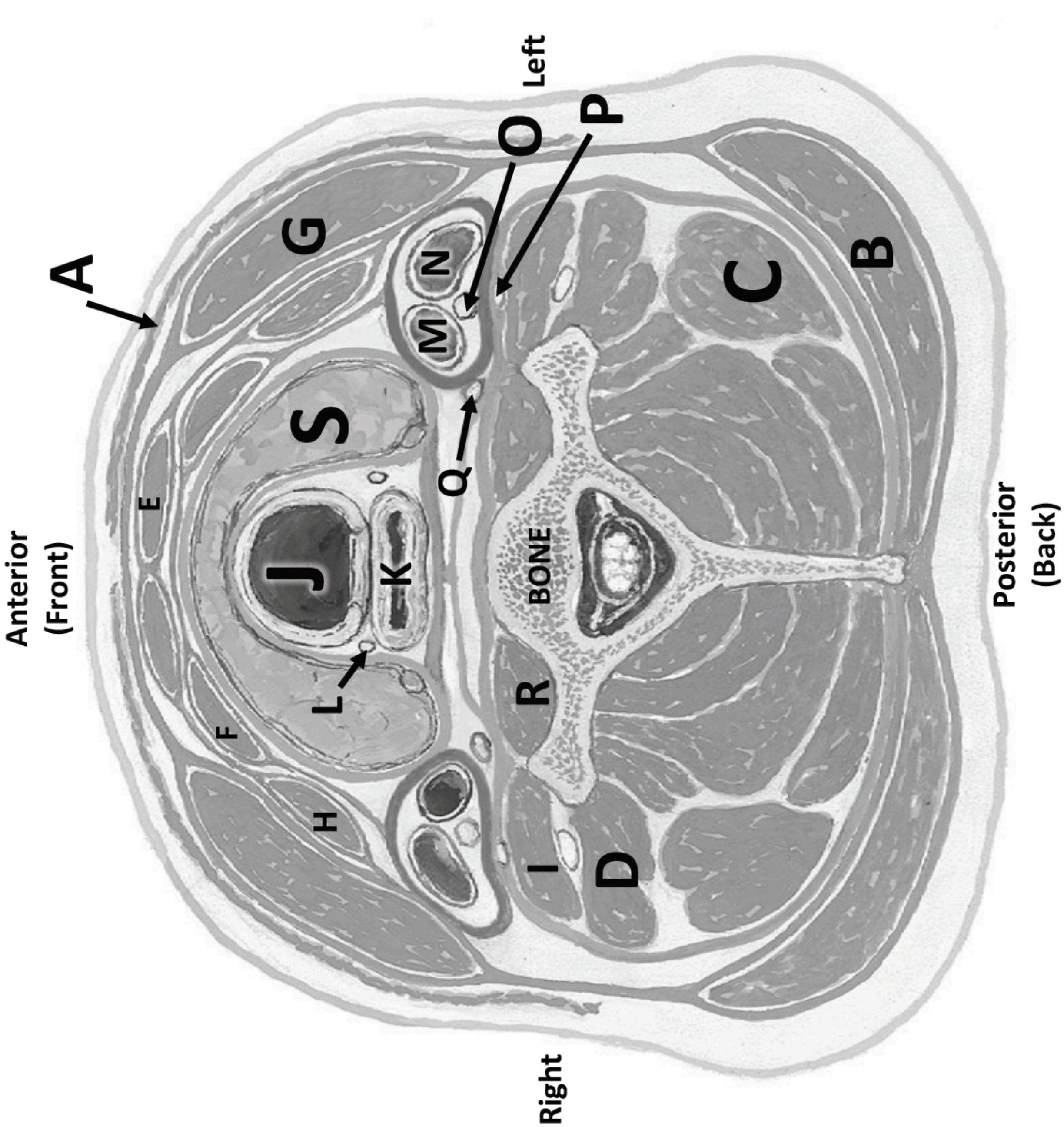
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Anterior (Front) View
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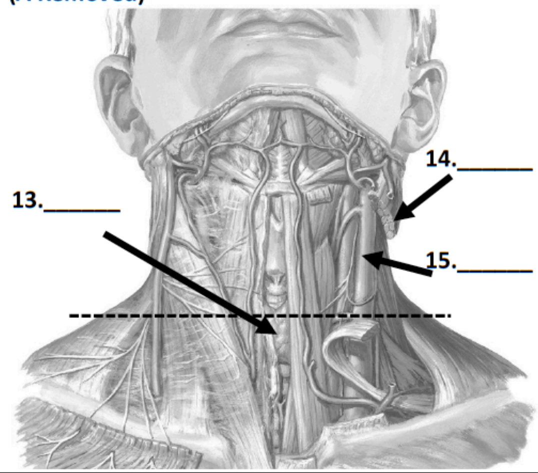
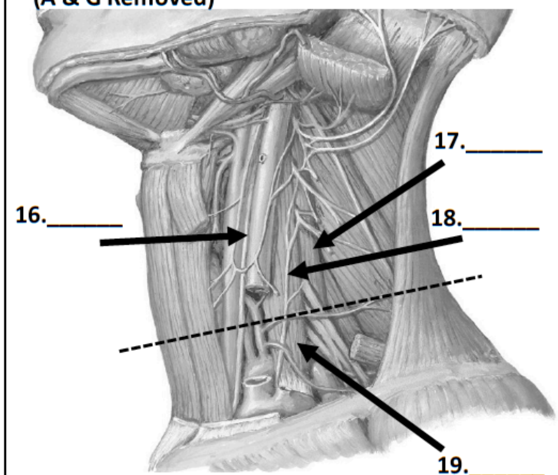
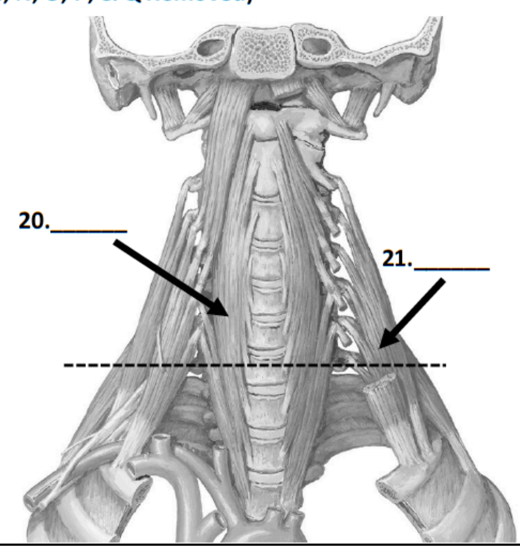


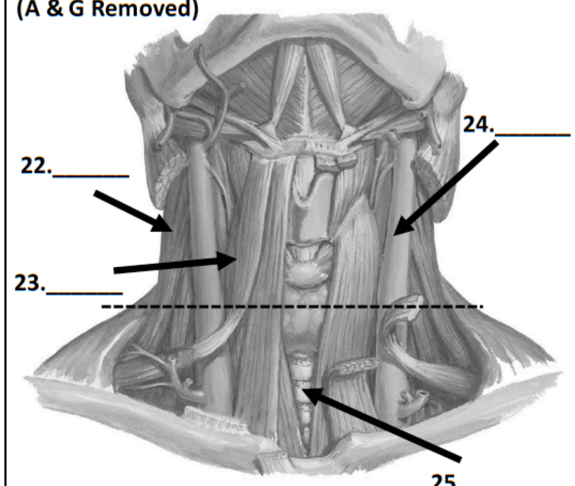
Left Side View
(A & G Removed)



Anterior (Front) View
(A, B, C, E, F, G, H, J, K, L, M, N, O, P, & Q Removed)



Anterior (Front) View
(A & G Removed)



Summative Assessments

In-Class Quiz #1: Thoracic Limb Muscles & Basic Biomechanics

This is an individual, closed-book, closed-note quiz.
Each question has one correct answer.
There are five questions, worth 1pt each.

~ Do not forget to list one concept under the "Muddiest Point" ~

NAME____________________________ **UIN**____________________________

1. A muscle's body arises directly from the cranial humerus. The muscle attaches to the distal radius via a strong band of dense regular connective tissue. When the muscle contracts, the radius moves closer to the humerus. Which of the following correctly describes the muscle's attachment to the humerus?

    a. Fleshy origin
    b. Fleshy insertion
    c. Tendinous origin
    d. Tendinous insertion
    e. Aponeurotic origin
    f. Aponeurotic insertion

2. Muscle "A" originates on the lateral epicondyle of the humerus and inserts on the metacarpal bones, but it does not cross the flexor surface of the carpal joint. What is the action of muscle "A" on the carpal joint?

    a. Flex
    b. Extend
    c. No Effect

3. Which of the following *best* describes the location of the cranial muscles of the arm?

    a. They cross the flexor surface of the shoulder joint
    b. They do not cross the flexor angle of the shoulder joint
    c. They cross the flexor surface of the elbow joint
    d. They do not cross the flexor angle of the elbow joint

Use the following description to answer questions 4 & 5.

There are three bones in a limb, in order of *most proximal to most distal*, the bones are:

- **Bone A**
- **Bone B**
- **Bone C**

There are two joints in the limb:

- **Joint D** is between *bones A and B*
    - its flexor angle faces *cranially*
- **Joint E** is between *bones B and C*
    - its flexor angle faces *cranially*

There are three muscles in the limb:

- **Muscle X** originates on the *cranial aspect of bone B* and inserts on *the cranial aspect of bone C*.
- **Muscle Y** originates on the *caudal aspect of bone A* and inserts on the *caudal aspect of bone C*.
- **Muscle Z** originates on the *caudal aspect of bone B* and inserts on the *caudal aspect of bone C*.

4. If **Muscle Y** and **Muscle Z** contract at the same time, one of the muscles is acting as an agonist and the other muscle is acting as a(n) _______________.

    a. antagonist
    b. fixator
    c. synergist

5. For **Muscle X** to flex **Joint E**, **Muscle Y** must ____________ which means that, in this situation, **Muscle X** is acting as a(n) ___________ while **Muscle Y** is acting as a(n) ____________ to the action of **Muscle X** at **Joint E**.

    a. contract simultaneously/antagonist/antagonist
    b. relax/antagonist/fixator
    c. relax/agonist/antagonist
    d. contract simultaneously/agonist/fixator

Muddiest Point:

Please list only one concept or objective that you felt was most difficult to understand during this lecture:

____

____

In-Class Quiz #2: Skeletal Muscle Histology & Physiology

This is an <u>individual</u>, <u>closed-book</u>, <u>closed-note</u> quiz.
Each question has <u>one</u> correct answer.
There are <u>five questions</u>, worth 1pt each.

~ Do not forget to list one concept under the "Muddiest Point" ~

Circle your section: ***Mon/Wed 8am*** ***Mon/Wed 10:20am*** ***Tues/Thurs 8am***

NAME______________________________ **UIN**______________________________

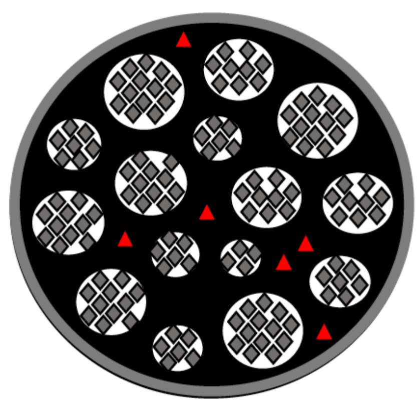
1. While performing surgery on a sperm whale (really tough skin), you must make a skin incision that is exactly one quarter inch long, one inch deep and in a perfectly straight line. The muscle you must use is composed of the following motor units:
   - Ten (10) type A motor units: 30 muscle cells each
   - Ten (10) type B motor units: 10 muscle cells each

   First, you recruit all ten (10) type A motor units and three (3) type B motor units, but the cut is not deep enough and it is not in a straight line. Which of the following combinations should you recruit when you try again?

   a. All ten type B motor units and eight type A motor units.
   b. Five type B motor units and five type A motor units.
   c. All ten type A motor units and only one type B motor unit.

2. The image on the right is a diagram of a cross section of a skeletal muscle. Based on their location, what do the red triangles most likely represent? Where are they located?

   a. muscle cells in the perimysium
   b. nerves in the epimysium
   c. blood vessels in the epimysium
   d. muscle cells in the endomysium
   e. blood vessels in the perimysium
   f. nerves in the endomysium



3. Which of the following molecules would you expect to find in an I band?

    a. Myosin
    b. Troponin C
    c. Acetylcholine

4. Acetylcholinesterase is an enzyme that breaks down acetylcholine at the synaptic cleft. If this enzyme is produced in excess and not being removed from any of the synaptic clefts and neuromuscular junctions of the brachialis muscle, what would you expect to occur?

    a. Difficulty extending the shoulder joint
    b. Difficulty extending the elbow joint
    c. Difficulty flexing the elbow joint
    d. Difficulty flexing the shoulder joint

5. A muscle is made up of 30 muscle cells and 5 motor units (motor units A, B, C, D, E). Motor units A, B & C are recruited during contraction of the muscle. This means that __________ is released at the ___________ associated with motor units A, B & C and the cells innervated will contract ___________.

    a. calcium / sarcomere / partially
    b. calcium / sarcomere / completely
    c. acetylcholine / neuromuscular junction / completely
    d. acetylcholine / neuromuscular junction / partially

Muddiest Point:

Please list only one concept or objective that you felt was most difficult to understand during this lecture:

____

____

In-Class Quiz #3: The Peripheral Nervous System

This is an <u>individual</u>, <u>closed-book</u>, <u>closed-note</u> quiz.
Each question has <u>one</u> correct answer.
There are <u>five questions</u>, worth 1pt each.

~ Do not forget to list one concept under the "Muddiest Point" ~

Circle your section: ***Mon/Wed 8am*** ***Mon/Wed 10:20am*** ***Tues/Thurs 8am***

NAME____________________________ **UIN**____________________________

1. A neuron receives temperature information from the skin on the lateral aspect of the arm. Which if the following best describes this neuron?

   a. It is an afferent, somatic, neuron of the central nervous system.
   b. It is an efferent, somatic, neuron of the peripheral nervous system.
   c. It is an afferent, visceral, neuron of the central nervous system.
   d. It is an efferent, visceral, neuron of the peripheral nervous system.
   e. It is an afferent, somatic, neuron of the peripheral nervous system.
   f. It is an efferent, visceral, neuron of the central nervous system.

2. A woman complains of a large lump on the back of her knee which seems to be causing weakness in the muscles of her lower limb. A nerve biopsy of the lump reveals areas with large, spiraling, layers of organelles, each separated by a plasma membrane. Based on the morphology and the symptoms, which of the following is the most likely diagnosis?

   a. A schwannoma affecting multipolar neurons.
   b. A pseudounipolar neuroma affecting multipolar neurons.
   c. A multipolar neuroma affecting multipolar neurons.
   d. A schwannoma affecting pseudounipolar neurons.
   e. A pseudounipolar neuroma affecting pseudounipolar neurons.
   f. A multipolar neuroma affecting pseudounipolar neurons.

3. While examining a histological slide, you see many isolated cell bodies. There is only one cytoplasmic process exiting each of the cell bodies. Assuming the slide is from a cross section of a spinal nerve, which of the following most likely describes what you are looking at?

   a. An afferent neuronal cell body located in the dorsal branch.
   b. An afferent neuronal cell body located in the ventral root.
   c. An afferent neuronal cell body located in the dorsal root ganglion.
   d. An efferent neuronal cell body located in the dorsal branch.
   e. An efferent neuronal cell body located in the ventral root.
   f. An efferent neuronal cell body located in the dorsal root ganglion.

4. Imaging reveals a tumor in the white matter of the ventral spinal cord at the C7 level which is compressing the nearby root of a spinal nerve. Because __________ are being affected, this patient will most likely present with ____________ of the ____________ limb.

    a. multipolar neuronal cell bodies / weakness / pelvic limb
    b. pseudounipolar neuronal cell bodies / numbness / thoracic limb
    c. multipolar neuronal cell bodies / weakness / pelvic limb
    d. myelinated axons of multipolar neurons / weakness / thoracic limb
    e. myelinated axons of pseudounipolar neurons / numbness / thoracic limb
    f. pseudounipolar neuronal cell bodies / numbness / pelvic limb

5. Which of the following would you expect to find in the ventral root of a spinal nerve

    a. Axon of a multipolar neuron
    b. Cell body of a multipolar neuron
    c. Axon of a pseudounipolar neuron
    d. Cell body of a pseudounipolar neuron

Muddiest Point:

Please list only one concept or objective that you felt was most difficult to understand during this lecture:

____

____

In-Class Quiz #4: Integration & Application

This is an <u>individual</u>, <u>closed-book</u>, <u>closed-note</u> quiz.
Each question has <u>one</u> correct answer.
There are <u>ten questions</u>, worth 0.5pt each.

~ Do not forget to list one concept under the "Muddiest Point" ~

NAME____________________________ **UIN**____________________________

Use the following case vignette to determine the answers to the questions:

HISTORY:
A 14-year-old male baseball player has experienced pain in the proximal right forearm for several months. The pain has progressively worsened and was eventually accompanied by significant swelling.

PHYSICAL EXAM:
Right forearm has significant swelling, pain, and tenderness.
The patient is able to flex and extend the right elbow joint with a 15-100° range of motion (compared to 0-140° in the left elbow). The muscles of the right forearm are of normal size, and there is no evidence of nerve or vascular damage.

DIAGNOSTIC TESTS:
1. **Radiographs (x-rays)** of the right forearm revealed loose fragments of bone in the region of the elbow and a possible defect at the capitulum.
2. **A computed tomography scan (CT)** revealed a loose body in the elbow joint as well as cracks in the cartilage and underlying bone of the capitulum – a condition referred to as <u>osteochondritis dissecans</u>.

DIAGNOSIS: Osteochondritis Dissecans

TREATMENT:
Arthroscopic evaluation of the elbow joint is initially performed. The patient was put under general anesthesia, and the right arm is suspended and two portals into the joint were made: one anterolaterally, (3 cm distal to and 2cm anterior to the lateral humeral epicondyle) and one medial (inside-to-outside). Visualization of the lesion on the capitulum is unsuccessful and the decision is made to perform an **arthrotomy.**
During the arthrotomy, the right arm was suspended in **full extension** and a tourniquet is used to elevate the muscles originating on the lateral epicondyle. The loose body was located and removed and the capitulum was debrided scraped).

POSTSURGICAL EXAMINATION:
1. The patient is unable to lift his hand/extend his wrist. (This inability to lift the hand is called wrist drop).
2. The patient also has complete paralysis of the posterior forearm muscles (corresponds to craniolateral antebrachium in dogs)
3. Sensation in the region of the entire forearm was normal.

This issue persisted for 6 weeks following the surgery. During this time you perform nerve conduction studies (electrodes on the skin above nerves that send a small shock through the nerve to measure the speed of conduction of the nerve) as well as electromyographies (electrodes inserted into the muscle to measure nerve activity) to classify the problem and determine its source.

(Adapted from: A Case Report and Review of the Literature by Papilion, Neff & Shall)

1. You suspect the patient has nerve damage due to prolonged compression during surgery. A. Which nerve will you evaluate? B. If the nerve conduction test results show a marked decrease in conduction velocity (speed), what may be damaged?
    a. radial nerve; schwann cells
    b. radial nerve; pseudounipolar PNS process
    c. ulnar nerve; schwann cells
    d. ulnar nerve; pseudounipolar PNS process

2. The patient returns in a week for a follow up examination. During a functional electrical stimulation test of the posterior forearm muscles (corresponds to craniolateral antebrachium in dogs) you notice an abnormal focal bulge just under the skin that only occurs when the muscles contract. The most likely cause is a fascial tear that occurred during the arthrotomy. Which layer is most definitely torn?
    a. epimysium
    b. perimysium
    c. endomysium

3. In order to explain the postsurgical symptoms observed in this patient, which segment of the spinal nerve is most likely damaged?
    a. dorsal root
    b. ventral root
    c. ventral branch
    d. dorsal branch

4. Based on the postsurgical symptoms, which type of neuron in the spinal nerve is damaged and which type is unaffected?
    a. pseudounipolar / multipolar
    b. pseudounipolar/bipolar
    c. bipolar / multipolar
    d. bipolar/pseudounipolar
    e. multipolar/bipolar
    f. multipolar/pseudounipolar

5. During the postsurgical examination, you ask the patient to flex his right elbow and then actively extend his right elbow. What is the most likely result?
    a. able to flex elbow joint/able to actively extend elbow joint
    b. able to flex elbow joint/unable to actively extend elbow joint
    c. unable to flex elbow joint/unable to actively extend elbow joint
    d. unable to flex elbow joint/able to actively extend elbow joint

6. A review of the patient's history prior to surgery suggests that he might have an adverse reaction to general anesthesia referred to as malignant hyperthermia (results in muscle rigidity, high fever, and tachycardia). To reduce risk of this occurring, a muscle relaxant, which is specifically designed to avoid motor neurons and all the components of neuromuscular junctions, is administered. Which of the following mechanisms could explain the effect of the drug used?
    a. It blocks the release of calcium into the sarcoplasm (cytoplasm) of the muscle cells.
    b. It blocks the receptors found on the sarcolemma (plasma membrane) of the muscle cells.
    c. It blocks the release of acetylcholine into the sarcoplasm (cytoplasm) of the muscle cells.
    d. It depletes the muscle cells of acetylcholine.
    e. It blocks the receptors for acetylcholine on troponin C.
    f. It depletes the area surrounding muscle cells of calcium.

7. While elevating the origin of the muscles near the capitulum, the muscles spontaneously contract, causing them to over-stretch. To determine if any damage was done, you run a nerve conduction study and an electromyography on the muscles and find that the nerves are fine and the muscle cells are depolarizing as normal, but the muscles still do not contract. Which muscles are you assessing? What would a biopsy of these muscles most likely reveal?
    a. extensors of the wrist / no thin filaments in the A band
    b. extensors of the wrist / no thick filaments in the A band
    c. flexors of the wrist / no myosin in the thick filaments
    d. flexors of the wrist / no thin filaments in the A band
    e. extensors of the wrist / no myosin in the thick filaments
    f. flexors of the wrist / no thick filaments in the A band

8. To determine whether other structures are damaged, you would like to test some of the anterior muscles of the forearm (correspond to the caudomedial muscles in the dog). To do this, you ask the patient to extend his arm out in front of him with his palm down. However, it is difficult to determine whether other structures are damaged with the wrist in a flexed position (due to the wrist drop the patient demonstrates). Assuming electrodes inserted into muscles cause them to contract, which muscle should you place an electrode in to determine whether the distal actions of the deep digital flexor muscle are intact? Testing the action of which of the flexor muscles would require you to remove the electrode?
    a. extensor carpi radialis m. / flexor carpi ulnaris m.
    b. common digital extensor m. / superficial digital flexor m.
    c. extensor carpi radialis m. / superficial digital flexor.
    d. flexor carpi ulnaris m. / flexor carpi radialis m.
    e. superficial digital flexor m. / common digital extensor m.

9. Which nerve is most likely damaged? Where are the cell bodies of the affected neuron located?
    a. the radial nerve / in the grey matter of the spinal cord
    b. the ulnar nerve / in the dorsal root ganglion
    c. the radial nerve / in the dorsal root ganglion
    d. the ulnar nerve / in the grey matter of the spinal cord
    e. the median nerve / in the grey matter of the spinal cord
    f. the median nerve / in the dorsal root ganglion

10. Which of the following correctly describes the neurons that are damaged?
    a. they are somatic, efferent, neurons damaged in the peripheral nervous system
    b. they are somatic, afferent, neurons damaged in the peripheral nervous system
    c. they are somatic, efferent, neurons damaged in the central nervous system
    d. they are somatic, afferent, neurons damaged in the central nervous system

Muddiest Point:

Please list only one concept or objective that you felt was most difficult to understand during this lecture:

___

___

Muscle Descriptors – Objectives 1 & 2

Obj. 1: Define the terms origin, insertion, action, tendon, aponeurosis, belly, and head.
(Level 1 - Remember)

Obj. 2: Use the above terms to describe three ways that muscle attaches to bone.
(Level 2 - Apply)

Question Level: Level 2 – Applying: use information in a new (but similar) situation.

1. A muscle's body arises from the caudal skull via a strong band of dense regular connective tissue. The muscle attaches to the boney ridge on the lateral aspect of the scapula. When the muscle contracts, it moves the scapula cranially. Which of the following correctly describes the muscle's attachment to the scapula?
    a. Fleshy origin
    b. Fleshy insertion
    c. Tendinous origin
    d. Tendinous insertion
    e. Aponeurotic origin
    f. Aponeurotic insertion

Flexor Angles – Objectives 1 & 2

- **Obj. 1: Define** the terms flexor angle and flexor surface.
  (Level 1 - Remember)
- **Obj. 2: Determine** the location of the flexor angles of joints of the thoracic limb and the relevance to muscle groups actions.
  (Level 2 – Apply)

Muscle Descriptors - Obj. 1: Define the terms origin, insertion, action, tendon, aponeurosis, belly, and head.
(Level 1 - Remember)

Question Level: Level 3 – Analyzing: Take information apart and explore relationships

2. Muscle "A" originates on the greater tubercle of the humerus and inserts on the ulna and radius, but it does not cross the flexor surface of the elbow joint. What is the action of muscle "A"?
    a. Move the humerus by flexing the elbow joint
    b. Move the radius and ulna by flexing the elbow joint
    c. Move the humerus by extending the elbow joint
    d. Move the radius and ulna by extending the elbow joint.

Flexor Angles – Objectives 1 & 2

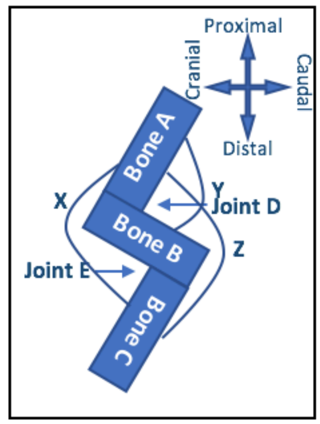
- **Obj. 1: Define** the terms flexor angle and flexor surface.
  (Level 1 – Remember)
- **Obj. 2: Determine** the location of the flexor angles of joints of the thoracic limb and the relevance to muscle groups actions.
  (Level 2 – Apply)

Question Level: Level 2 – Apply: use information in a new (but similar) situation.

3. Which of the following *best* describes the location of the lateral shoulder muscles?
   a. They cross the flexor surface of the shoulder joint
   b. They do not cross the flexor angle of the shoulder joint
   c. They cross the flexor surface of the elbow joint
   d. They do not cross the flexor angle of the elbow joint

Use the following description to answer questions 4 & 5.

There are three bones in a limb, in order of *most proximal to most distal*, the bones are:



- **Bone A**
- **Bone B**
- **Bone C**

There are two joints in the limb:

- **Joint D** is between *bones A and B*
  - its flexor angle faces *caudally*
- **Joint E** is between *bones B and C*
  - its flexor angle faces *cranially*

There are three muscles in the limb:

- **Muscle X** originates on the *cranial aspect of bone A* and inserts on *the cranial aspect of bone C*.
- **Muscle Y** originates on the *caudal aspect of bone A* and inserts on the *caudal aspect of bone B*.
- **Muscle Z** originates on the *caudal aspect of bone A* and inserts on the *caudal aspect of bone C*.

Biomechanics – Objective 1

- **Obj. 1: Define** terms related to biomechanics including agonists, antagonist, synergist, prime mover, and fixator muscles.
  (Level 1 - Remember)

Question Level: Level 2 – Apply: use information in a new (but similar) situation.

4. If **Muscle Y** and **Muscle X** contract at the same time, one of the muscles is acting as an agonist and the other muscle is acting as a(n) _______________.
   a. antagonist
   b. fixator
   c. synergist

Biomechanics – Objectives 1 & 2

- **Obj. 1: Define** terms related to biomechanics including agonists, antagonist, synergist, prime mover, and fixator muscles.
  (Level 1 - Remember)
- **Obj. 2: Use** biomechanical terms to **describe** individual and combined actions of muscles of the thoracic limb.
  (Levels 1 & 2 – Apply & Remember)

Question Level: Level 3 – Evaluate: Critically examine information and make judgements.

5. For **Muscle X** to flex **Joint E**, but not extend **Joint D**, **Muscle Y** must ____________ which means that, in this situation, **Muscle X** is acting as a(n) ___________ while **Muscle Y** is acting as a(n) ____________ to the action of **Muscle Y** at **Joint D**.
   a. contract simultaneously/antagonist/antagonist
   b. relax/antagonist/fixator
   c. relax/agonist/antagonist
   d. contract simultaneously/agonist/fixator

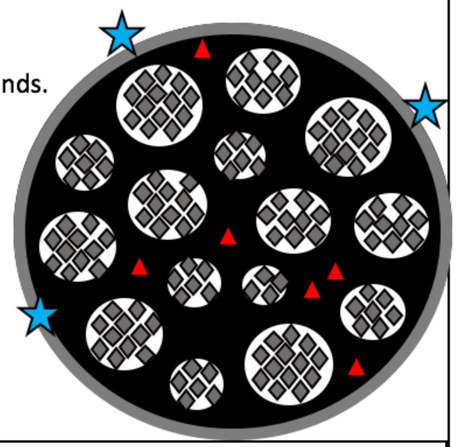
Tissue Organization – Objectives 1 & 2

Obj. 1: Diagram and **label** a cross section of a skeletal muscle including connective tissue layers. *(Levels 1 & 3 – Remember & Analyze)*

Obj. 2: List the major functions of connective tissue in skeletal muscle. *(Level 2 - Apply)*

Question Level: Level 2 – Applying: use information in a new (but similar) situation.

1. The image on the right is a diagram of a cross section of a skeletal muscle. Based on the location, which of the following is most likely true about the blue stars?
    a. They are covered by endomysium.
    b. They could be seen grossly.
    c. They have the same function as the grey diamonds.
    d. They are contractile cells.
    e. They are axon terminals.



Muscle Cell Innervation – Objectives 1 & 2

- **Obj. 1: Define** the terms recruitment, neuromuscular junction (a.k.a. motor end plate), and motor unit (a.k.a. motor unit ratio). *(Level 1 - Remember)*
- **Obj. 2: Explain** the "all or none" principle as it applies to skeletal muscle contraction. *(Level 2 – Understand)*

Mechanism of Contraction - Obj. 1: Explain the basic mechanism of contraction (the *Sliding Filament Theory*) for skeletal muscle including the basic molecular components. *(Level 2 - Understand)*

Question Level: Level 3 – Analyze: take information apart & explore relationships.

2. A muscle is made up of 50 muscle cells and 3 motor units (motor units A, B, C). Motor units B & C are recruited during contraction of the muscle. This means that an action potential is sent down ______ axons, causing __________ to be released into the sarcoplasm (cytoplasm) of the muscle cells, causing all the ____________ within each cell to contract completely.
    a. two / calcium / sarcomeres
    b. three / acetylcholine / sarcomeres
    c. fifty / calcium / motor units
    d. two / acetylcholine / sarcomeres
    e. three / calcium / motor units
    f. fifty / acetylcholine / motor units

Control of Muscle Contraction – Objectives 1 & 2

- **Obj. 1: Compare & contrast** the control a given muscle has (i.e. fine vs. course) based on the given motor unit ratios.
  (Level 3 – Evaluate)
- **Obj. 2: Outline** how the force of contraction in skeletal muscle can be regulated.
  (Level 3 – Analyze)

Question Level: Level 3 – Evaluating: Critically examine information and make judgements.

3. While performing surgery on a sperm whale (really tough skin), you must make a skin incision that is exactly one quarter inch long, one inch deep and in a perfectly straight line. The muscle you must use is composed of the following motor units:
   - Fifteen (15) type A motor units: 30 muscle cells each
   - Thirty (30) type B motor units: 10 muscle cells each

   First, you recruit all fifteen (15) type A motor units and fifteen (15) type B motor units, but the cut is too deep and too long. Which of the following combinations should you recruit when you try again?
   a. Ten (15) type A motor units and all fifteen (15) type B motor units.
   b. All fifteen (15) type A motor units and no type B motor units.
   c. **Five (5) type A motor units and all fifteen (15) type B motor units.**

Mechanism of Contraction – Objective 1

- **Obj. 1: Explain** the basic mechanism of contraction (the *Sliding Filament Theory*) for skeletal muscle including the basic molecular components.
  (Level 2 - Understand)

Question Level: Level 1 – Remember: Find or remember information.

4. Which of the following molecules are part of a crossbridge?
   a. Calcium
   b. **Actin**
   c. Tropomyosin

Mechanism of Contraction – Objective 1

- **Obj. 1: Explain** the basic mechanism of contraction (the *Sliding Filament Theory*) for skeletal muscle including the basic molecular components.
  (Level 2 - Understand)

Lab Objective – Muscles of the Antebrachium: Identify the muscles of the antebrachium & **describe** their attachments and actions as groups. *(Level 1 – Remember)*

Question Level: Level 3 – Analyzing: Take information apart and explore relationships.

5. You are treating a patient recently diagnosed with myasthenia gravis – a hypersensitivity disorder caused by autoantibodies binding to acetylcholine receptors. This issue directly effects the __________ and examination of the function of the caudal (posterior) muscles of the arm would most likely reveal ________.
    a. thin filaments / difficulty extending the elbow against resistance
    b. neuromuscular junction / difficulty flexing the elbow
    c. thin filaments / difficulty flexing the elbow
    d. **neuromuscular junction / difficulty extending the elbow against resistance**

Divisions & Terminology – Objectives 1 & 2

- **Obj. 1: Describe** the anatomical and functional divisions of the nervous system.
  (Level 1 - Remember)
- **Obj. 2: Explain** afferent, efferent, somatic, and visceral and **determine** which neurons may be associated.
  (Level 2 – Understand & Apply)

Question Level: Level 3 – Analyzing: take information apart and explore relationships.

1. A neuron sends an impulse from an autonomic ganglion to a smooth muscle cell in the colon, causing it to contract. Which if the following best describes this neuron?
    a. It is an afferent, somatic, neuron of the central nervous system.
    b. It is an efferent, somatic, neuron of the peripheral nervous system.
    c. It is an afferent, visceral, neuron of the central nervous system.
    d. It is an efferent, visceral, neuron of the peripheral nervous system.
    e. It is an afferent, somatic, neuron of the peripheral nervous system.
    f. It is an efferent, visceral, neuron of the central nervous system.

Cellular Components – Objectives 1 & 2

- **Obj. 1: Describe** the microscopic appearance of neurons and **classify** them based on cellular processes.
  (Level 1 - Remember)
- **Obj. 2: Explain** the basic function of Schwann cells.
  (Level 2 – Understand)

Question Level: Level 3 – Evaluating: Critically examine information & make judgements.

2. A woman complains of numbness in her right lower arm. A nerve conduction study (electrodes on the skin above nerves that send a small shock through the nerve to measure the speed of the nerve) and electromyography (electrodes inserted into the muscle to measure nerve activity) reveal that the muscles of the woman's arm are receiving impulses, but the impulses are moving very slowly. Which of the following cell types are most likely responsible for these issues?
    a. Schwann Cells
    b. Pseudounipolar Neurons
    c. Multipolar Neurons
    d. Epithelial Cells

The Spinal Nerve – Objectives 1 & 2

- **Obj. 1: Diagram** and **label** the somatic components of a spinal nerve.
  (Levels 1&3 – Remember & Analyze)
- **Obj. 2: Predict** deficits which would result from damage to specific portions of a spinal nerve.
  (Level 3 – Evaluate)

Question Level: Level 2 – Apply: use information in a new (but similar) situation.

3. While examining a histological slide, you see many large cell bodies. There are many processes off of the cell bodies. The axons of these neurons are most likely located in the ___________ and carry ___________ innervation.
    a. spinal cord / afferent
    b. spinal cord / efferent
    c. ventral root of a spinal nerve / afferent
    d. **ventral root of a spinal nerve / efferent**
    e. dorsal root ganglion of a spinal nerve / afferent
    f. dorsal root ganglion of a spinal nerve / efferent

Functional Organization Terminology – Objectives 1 & 2

- **Obj. 1: Describe** a nerve plexus and **identify** the plexuses associated with the thoracic and pelvic limbs.
  (Level 1 - Remember)
- **Obj. 2: Define, compare & contrast**, the following terms associated with the nervous system: Gray matter, white matter, ganglion, nucleus, tract, nerve.
  (Level 1 - Remember)

The Spinal Nerve – Objectives 2: Predict deficits which would result from damage to specific portions of a spinal nerve. *(Level 3 – Evaluate)*

Question Level: Level 3 – Analyzing: take information apart and explore relationships.

4. Imaging reveals a tumor in the white matter of the dorsal spinal cord at the C7 level which is compressing the nearby root of a spinal nerve just as it is about to pass through the intervertebral foramen. Because __________ are being affected, this patient will most likely present with ____________ of the ____________ limb.
    a. multipolar neuronal cell bodies / weakness / pelvic limb
    b. pseudounipolar neuronal cell bodies / numbness / thoracic limb
    c. myelinated axons of multipolar neurons / weakness / thoracic limb
    d. **myelinated axons of pseudounipolar neurons / numbness / thoracic limb**
    e. pseudounipolar neuronal cell bodies / numbness / pelvic limb

The Spinal Nerve – Objectives 1

- **Obj. 1: Diagram** and **label** the somatic components of a spinal nerve.
  (Levels 1&3 – Remember & Analyze)

Cellular Components – Objectives 1

- **Obj. 1: Describe** the microscopic appearance of neurons and **classify** them based on cellular processes.
  (Level 1 - Remember)

Question Level: Level 1 – Remember: find or remember information.

5. Which of the following would you expect to find in the grey matter of the spinal cord?
    a. Axon of a multipolar neuron
    b. **Cell body of a multipolar neuron**
    c. Axon of a pseudounipolar neuron
    d. Cell body of a pseudounipolar neuron

Use the following case vignette to determine the answers to the questions:

PHYSICAL EXAM:
A 50-year-old male is admitted to the hospital after experiencing progressive muscle weakness in his wrists and fingers.

The patient's forearms and fingers of both upper limbs are swollen (inflammation present), and he has difficulty flexing the wrists and the digital joints. He does have full mobility in his shoulders and elbows.

HISTORY:
A careful history of the patient reveals that both his mother and grandfather suffer from diabetes. Because prolonged hyperglycemia (high blood sugar) can cause the small blood vessels supplying peripheral nerves to leak, the condition can also lead to ischemia (inadequate blood supply) and eventually necrosis (death) of the nerves.

DIAGNOSTIC TESTS:
Blood Test: Slightly elevated level of creatine kinase (an enzyme which leaks out of muscle cells when they are damaged)

Muscle biopsy: shows Inclusion bodies between the muscle cells as well as intracytoplasmic inclusions which confirms your suspicion *– this patient has inclusion-body myositis (IBM).*

Diabetes tests: Blood tests, sensory testing, nerve conduction studies (electrodes on the skin above nerves that send a small shock through the nerve to measure the speed of the nerve), and an electromyography (electrodes inserted into the muscle to measure nerve activity) were not consistent with diabetes.

All of the questions on this quiz are considered "Level 3", requiring students to do one or more of the following:

- **Create –** use information to create something new
- **Evaluate** – critically examine information & make judgements
- **Analyze** – take information apart and explore relationships

The *primary* objective being evaluated is listed above each question, but each question is designed to evaluate the students' ability to integrate and apply information given in the case vignette and/or in class.

Cellular Components – Objectives 1

- **Obj. 2: Explain** the basic function of Schwann cells.
  (Level 2 - Understand)

Just like muscles, nerves are organized into groups of axons called fascicles and covered in connective tissue layers – epineurium, perineurium and endoneurium. Where is the most likely location of the vessels that leak when a patient has prolonged hyperglycemia? Where are the neurons receiving the nutrients supplied by the blood vessels?

a. **perineurium / between successive Schwann cells**
b. inside of the Schwann cells / along the entire axon
c. in the white matter of the spinal cord / at the cell body

Tissue Organization – Objectives 1 & 2

- **Obj. 1: Diagram** and **label** a cross section of a skeletal muscle including connective tissue layers.
  (Levels 1 & 3 – Remember & Analyze)
- **Obj. 2: List** the major functions of connective tissue in skeletal muscle.
  (Level 2 - Apply)

  Before performing the muscle biopsy you inject a local anesthetic and accidently inject the anesthetic into the muscle. Which of the following sequences describes the correct order of tissue layers pierced by the needle, passing from superficial to deep?

  a. **Epidermis, dermis, epimysium, perimysium, endomysium**
  b. Dermis, epidermis, epimysium, perimysium, endomysium
  c. Epidermis, dermis, perimysium, endomysium, epimysium
  d. Dermis, epidermis, perimysium, endomysium, epimysium
  e. Epidermis, dermis, endomysium, epimysium, perimysium
  f. Dermis, epidermis, endomysium, epimysium, perimysium

The Spinal Nerve – Objectives 1 & 2

- **Obj. 1: Diagram** and **label** the somatic components of a spinal nerve.
  (Levels 1&3 – Remember & Analyze)
- **Obj. 2: Predict** deficits which would result from damage to specific portions of a spinal nerve.
  (Level 3 – Evaluate)

Mechanism of Contraction – Objective 1

- **Obj. 1: Explain** the basic mechanism of contraction (the *Sliding Filament Theory*) for skeletal muscle including the basic molecular components.
  (Level 2 - Understand)

With IBM, there are multiple intracytoplasmic inclusions inside of the muscle cells. This implies that the action of which of the following molecules is impaired? What transmission would be interrupted if there were damage to the ventral root of the spinal nerve?

a. **troponin C / acetylcholine to the muscle cell**
b. tropomyosin / acetylcholine to the muscle cell
c. acetylcholine / an electrical signal to the CNS
d. troponin C / an electrical signal to the CNS
e. tropomyosin / an electrical signal to the CNS
f. acetylcholine / acetylcholine to the muscle cell

Cellular Components – Objectives 1 & 2

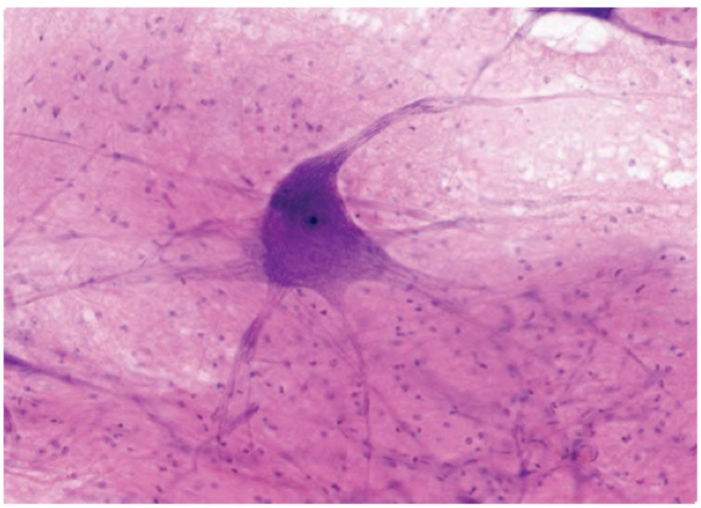
- **Obj. 1: Describe** the microscopic appearance of neurons and **classify** them based on cellular processes. *(Level 1 - Remember)*

Divisions & Terminology – Objective 2

- **Obj. 2: Explain** afferent, efferent, somatic, and visceral and **determine** which neurons may be associated.
  (Level 2 – Understand & Apply)

After many years living with IBM, the patient expires and an autopsy is done. The image below is a section on the patient's spinal cord. Which of the following best describes what you are looking at?

a. **an efferent neuron in the grey matter of the spinal cord**
b. an afferent neuron in the dorsal root ganglion
c. an efferent neuron in the white matter of the spinal cord
d. an afferent neuron in the grey matter of the spinal cord
e. an efferent neuron in the dorsal root ganglion
f. an afferent neuron in the white matter of the spinal cord



Flexor Angles – Objectives 1 & 2

- **Obj. 1: Define** the terms flexor angle and flexor surface.
  (Level 1 - Remember)
- **Obj. 2: Determine** the location of the flexor angles of joints of the thoracic limb and the relevance to muscle groups actions.
  (Level 2 – Apply)

During the physical exam, you evaluate the patient's ability to actively extend the elbow joint. Which muscle group are you evaluating? What bony prominence would you palpate to evaluate the insertion of this muscle group?

a. Caudal (posterior) arm/ olecranon
b. Caudal (posterior) arm/coronoid process
c. Caudal (posterior) arm/styloid process
d. Cranial (anterior) arm/ olecranon
e. Cranial (anterior) arm/ coronoid process
f. Cranial (anterior) arm/styloid process

Mechanism of Contraction – Objective 1

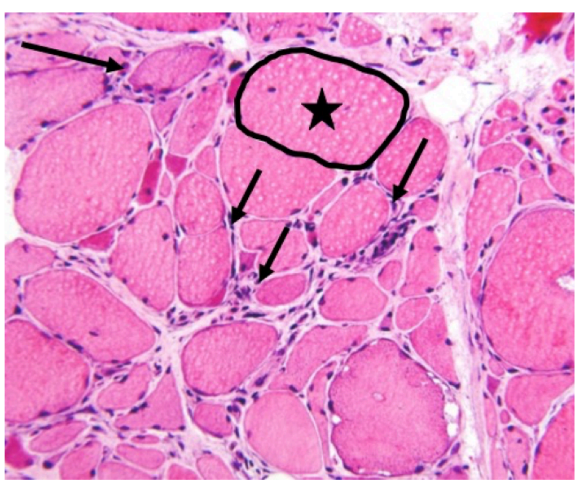
- **Obj. 1: Explain** the basic mechanism of contraction (the *Sliding Filament Theory*) for skeletal muscle including the basic molecular components.
  (Level 2 - Understand)

The image below is a biopsy of the muscle. The star is on a muscle cell, which is outlined in black. The arrows are pointing to immune cells. Based on the connective tissue layer being attacked by the immune cells, which aspect of skeletal muscle contraction does this interfere with?

a. the ability of the muscle cell's contraction to be transmitted to the rest of the muscle
b. the release of acetylcholine at the neuromuscular junction
c. the release of calcium inside of the sarcoplasm (cytoplasm) of the muscle cell
d. the ability of myosin to bind to actin and form a crossbridge

The white dots inside of the muscle cells are the intracytoplasmic inclusions seen between myofilaments in muscle cells of patients with IBM. Which aspect of skeletal muscle contraction does this interfere with?

a. the ability of the muscle cell's contraction to be transmitted to the rest of the muscle
b. the release of acetylcholine at the neuromuscular junction
c. the release of calcium inside of the sarcoplasm (cytoplasm) of the muscle cell
d. the ability of myosin to bind to actin and form a crossbridge



Biomechanics – Objective 2

- **Obj. 2: Use** biomechanical terms to **describe** individual and combined actions of muscles of the thoracic limb.
  (Levels 1 & 2 – Apply & Remember)

Lab Objective – Muscles of the Antebrachium: Identify the muscles of the antebrachium & **describe** their attachments and actions as groups. *(Level 1 – Remember)*

While performing the physical examination of the muscle function in the hand, you hold the proximal interphalangeal joint of the patient's finger in the extended position and instruct him to try to flex the distal interphalangeal joint. If the patient is unable to perform this task, you may suspect damage to which of the following muscle and nerve pairs?

a. Superficial digital flexor muscle / median nerve
b. Deep digital flexor muscle / radial nerve
c. Superficial digital flexor muscle / median & ulnar nerves
d. **Deep digital flexor muscle / median nerve**
e. Superficial digital flexor muscle / radial nerve

The Spinal Nerve – Objectives 1 & 2

- **Obj. 1: Diagram** and **label** the somatic components of a spinal nerve.
  (Levels 1&3 – Remember & Analyze)
- **Obj. 2: Predict** deficits which would result from damage to specific portions of a spinal nerve.
  (Level 3 – Evaluate)

Divisions & Terminology – Objective 1

- **Obj. 1: Describe** the anatomical and functional divisions of the nervous system.
  (Level 1 - Remember)

If the patient's symptoms are solely due to inclusion body myositis, which nerve function test results would you expect to be within the normal range? Which specific segment of the spinal nerve <u>is directly innervating</u> the thoracic limbs?

a. Somatic Afferent axons /in the ventral branch
b. Somatic Efferent axons/ in the ventral branch
c. Somatic Afferent axons/ in the dorsal branch
d. Somatic Efferent axons/ in the dorsal branch
e. **A and B**
f. C and D
g. B and D
h. A and C

Divisions & Terminology – Objective 1

- **Obj. 1: Describe** the anatomical and functional divisions of the nervous system.
  (Level 1 - Remember)

Before the muscle biopsy test results returned, the neurology resident suspected the patient had damage to his multipolar neuronal cell bodies and suggested testing the dorsal root ganglion (DRG). Should you follow the resident's suggestion?

a. Yes, because the multipolar cell bodies are in the PNS in the DRG
b. Yes, because the multipolar cell bodies are in the CNS in the DRG
c. No, because the multipolar cell bodies are in the PNS in a nucleus
d. **No, because the multipolar cell bodies are in the CNS in a nucleus**

Exam #1

NAME _______________________________

UIN __________________________________

Print your name and your UIN number on the **question sheet.** Bubble the letter of your exam and your UIN on the scantron. **Both the question and answer sheet must be turned in** before the test will be graded. Answer as specifically as possible. Questions will only have one correct answer. You may write on the question sheet. Each question is worth 1.0 point. Exam is worth 25 points plus 2 bonus points.

1. Which collateral ligament must be ruptured to allow abnormal abduction of the digit at the level of the base of the second proximal phalanx of the right manus of a dog?
    a. Abaxial; metacarpophalangeal
    b. Abaxial; proximal interphalangeal
    c. Abaxial; distal interphalangeal
    d. Axial; metacarpophalangeal
    e. Axial; proximal interphalangeal
    f. Axial; distal interphalangeal

2. A canine patient got caught in a barbed wire fence and all of the tendons of insertion of the craniolateral muscles of the left forearm were severed (cut). What is **the most proximal action** that the dog is unable to do?
    a. Flex elbow joints
    b. Flex carpal joints
    c. Flex interphalangeal joints
    d. Extend elbow joint
    e. Extend carpal joints
    f. Extend interphalangeal joints

3. A canine patient is unable to flex any of the interphalangeal joints or carpal joints, but extension of the interphalangeal joints is normal. Which nerve or nerves could be damaged?
    a. Radial
    b. Median
    c. Ulnar
    d. A and B
    e. A and C
    f. B and C
    g. A, B, and C

4. A 3 year old male Rottweiler presents with left front limb lameness associated with the glenohumeral joint. You recommend complete kennel rest (no activity) for 2 months. Which tissue component of the shoulder joint is least likely to respond favorably (get better) following this treatment?
    a. Hyaline cartilage
    b. Bone
    c. Skeletal muscle
    d. Collateral Ligament

5. Because of the range of motion at the human shoulder joint and the subacromial location of the tendon of insertion of the supraspinatus muscle, what accessory structure is most likely associated with this tendon?
    a. Fibrocartilage disc
    b. Bursa
    c. Tendon sheath
    d. Sesamoid bone

6. Which of the following are synovial joints?
    a. Antebrachiocarpal
    b. Carpometacarpal
    c. Capitate to hamate
    d. A and B
    e. A and C
    f. B and C
    g. A, B, and C

7. A lump deep to the epidermis on the ventral abdomen is aspirated (cells removed) and the cells are determined to be adipocytes. Based on the cells, what basic tissue type is this lump and would it be expected to bleed if cut?
    a. Muscle; yes
    b. Muscle; no
    c. Connective; yes
    d. Connective; no
    e. Epithelial; yes
    f. Epithelial; no

8. Which of the following tissues do NOT have a direct blood supply?
    a. Simple squamous epithelium
    b. Bone
    c. Fibrocartilage
    d. Nerve
    e. A and B
    f. A and C
    g. B and C
    h. C and D

9. You cut yourself with the scalpel blade during lab. Bleeding will occur as soon as the blade reaches which layer?
    a. Epidermis
    b. Dermis
    c. Muscle

10. Where would a person with dentalgia most likely complain of feeling pain?
    a. Head
    b. Rib
    c. Hip
    d. Mouth

11. Radiographs (x-rays) of a 10 year old boy show a fractured (broken) olecranon of the elbow joint with posterior displacement of the bone fragment. This displacement is most likely due to contraction of which muscle?
    a. Brachioradialis
    b. Triceps brachii
    c. Biceps brachii
    d. Brachialis

12. Muscle X originates on the lateral epicondyle of the humerus of a dog and inserts on the styloid process of the radius, what is its action?
    a. Flex the carpals jts.
    b. Extend the carpal jts.
    c. Supinate the manus
    d. Pronate the manus

13. In order to amputate the forelimb of a dog, which extrinsic muscle(s) that attach to the spine of the scapula must be severed?
    a. Omotransversarius
    b. Deltoideus
    c. Supraspinatus
    d. A and B
    e. A and C
    f. B and C
    g. A, B and C

14. In humans, the palmaris longus muscle originates on the medial epicondyle of the humerus and inserts on the distal part of the retinaculum on the anterior surface (think anatomical position) of the wrist at the level of the carpal bones. What is the distal-most action of this muscle? DR PINE PEERWISE QUESTION
    a. Extend elbow jt.
    b. Extend carpal jts.
    c. Extend metacarpophalangeal joints
    d. Flex elbow jt.
    e. Flex carpal jts
    f. Flex metacarpophalangeal joints

15. A new drug is classified as a calcium reuptake inhibitor (prevents the reabsorption of calcium). Which of the following is most likely a possible side-effect of this drug?
    a. Muscle weakness
    b. Muscle stiffness
    c. Muscle Inflammation

Use the following information to answer the next 2 questions

- There are three bones in a limb, in order of most *proximal* to most *distal,* the bones are:
  Bone 1
  Bone 2
  Bone 3

- There are two joints in the limb:
  Joint X is between bones 1 and 2; its flexor angle opens caudally
  Joint Y is between bones 2 and 3; its flexor angle opens cranially

- There are two muscles in the limb:
  Muscle P originates on the cranial aspect of bone 2 and inserts on the cranial aspect of bone 3.
  Muscle Q originates on the caudal aspect of bone 1 and inserts on the caudal aspect of bone 2.

16. **Question:** If **Muscle P** and **Muscle Q** contract simultaneously, **Joint Y** will
    a. be fixed
    b. flex
    c. extend
    d. be unaffected

17. **Question:** If **Muscle P** and **Muscle Q** contract simultaneously, **Joint X** will
    a. be fixed
    b. flex
    c. extend
    d. be unaffected

18. There are two axons innervating one muscle. The first axon splits 20 times and sends a branch to 20 individual muscle fibers. The second axon splits 200 times and sends a branch to 200 individual muscle fibers. How many motor units are created?
    a. 2
    b. 20
    c. 200
    d. 220

19. A biopsy reveals regularly arranged filaments made up of mostly myosin and actin. The pathologist's notes mention visceral, efferent, innervation. Which of the following organs is the biopsy most like from?
    a. Biceps Brachii m.
    b. Stomach
    c. Heart
    d. Intestines
    e. Artery
    f.

Use the case vignette to answer questions 20 - 24

HISTORY
A 32 year old man who worked heavy manual labor complained of pain in the right shoulder region. The shoulder region muscles are easily fatigued and weak.
PHYSICAL EXAM:
There was (atrophy) wasting of the supraspinatus and infraspinatus muscles. Terminal range of arm abduction was slightly restricted.
DIAGNOSTIC TESTS:
Radiographs (X-rays) of the shoulder joint and routine blood tests were within normal limits.
Nerve conduction velocity tests and an electromyography (EMG) of the muscles were performed.

20. You perform an electromyography (EMG) on the supraspinatus muscle. Direct electrical muscle stimulation produces a normal contraction of the muscle cells. However, when the patient was asked to voluntarily produce the movement associated with this muscle, the contraction was significantly impaired. **Based on these results**, which neuron is definitely damaged?
    a. Afferent, somatic, multipolar
    b. Efferent, somatic, multipolar
    c. Afferent, visceral, multipolar
    d. Efferent, visceral multipolar
    e. Afferent, somatic, pseudounipolar
    f. Efferent, somatic, pseudounipolar
    g. Afferent, visceral, pseudounipolar
    h. Efferent, visceral, pseudounipolar

21. The myalgia and weakness the patient is experiencing is due to damage to which named nerve? Which portion of the spinal nerves contributing to the named nerve is most likely damaged?
    a. Axillary n; Dorsal branch
    b. Axillary n; Ventral branch
    c. Suprascapular n; Dorsal branch
    d. Suprascapular n; Ventral branch

22. The neurology resident wants to prescribe the patient a nondepolarizing drug which is a competitive antagonist (competes with) for acetyl choline. How should you respond to the resident's suggestion?
    a. Agree; this drug will increase calcium release within the muscle cell
    b. Disagree; this drug will increase calcium release within the muscle cell
    c. Agree; this drug will decrease calcium release within the muscle cell
    d. Disagree; this drug will decrease calcium release within the muscle cell

23. If the patient's symptoms are due to inflammation of the connective tissue directly surrounding fascicles, where is the inflammation and what other structure could be affected?
    a. Perimysium; Ganglion
    b. Epimysium; Ganglion
    c. Perimysium; Vein
    d. Epimysium; Vein
    e. A and C
    f. B and D

24. Assuming the attachment sites for the supraspinatus muscle are the same in the human and the dog, what type of attachment does it have at the origin, and where is the origin of the muscle?
    a. Tendinous; supraspinous fossa of scapula
    b. Tendinous; acromion of scapula
    c. Aponeurotic; supraspinous fossa of scapula
    d. Aponeurotic; acromion of scapula
    e. Fleshy; supraspinous fossa of scapula
    f. Fleshy; acromion of scapula

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25. ATP facilitates the pivot of the myosin heads as well as their detachment from the active site on myosin. Which of the following conditions is most likely caused by a complete depletion/unavailability of ATP?
    a. Rigor Mortis (muscle stiffening following death)
    b. Muscular Dystrophy (progressive muscle weakness)
    c. Tetanus (muscle spasms)
    d. Myasthenia Gravis (progressive muscle weakness and fatigue)

26. A postmortem biopsy report describes the presence of multiple neuronal cell bodies. Assuming this biopsy was taken from the peripheral nervous system, how would you classify the structure?
    a. Ganglion
    b. Nerve
    c. Tract
    d. Nucleus

27. A man walks into a bakery to smell the pies every morning. This morning, he slipped and hit his head outside the bakery. When he walked in, he noticed that he could not smell any of the baked goods, and had trouble hearing out of his right ear. Describe the type of neuron that he most likely injured during his fall. STUDENT SUBMITTED PEERWISE QUESTION
    a. Multipolar; afferent
    b. Multipolar; efferent
    c. Pseudounipolar; afferent
    d. Pseudounipolar; efferent
    e. Bipolar; afferent
    f. Bipolar; efferent

Lab Exam I

Bones (4)

1. Supraglenoid tubercle of scapula canine and human
2. Medial epicondyle of human and canine humerus is it right or left?
3. Styloid process of radius
4. Scaphoid bone of human

Ligaments (2)

5. Proximal digital annular ligament
6. lateral collateral ligament of the elbow joint

Joints (2)

7. Antebrachiocarpal joint
8. Proximal interphalangeal joint

Muscles (8)

9. Serratus ventralis on cadaver
10. Rhomboideus on cadaver
11. Deltoideus
12. Subscapularis
13. Brachialis
14. Accessory head of triceps brachii
15. Supinator
16. Flexor carpi ulnaris

Lymph Nodes (1)

17. Superficial cervical LN

Arteries (4)

18. Caudal circumflex humoral a.
19. Collateral ulnar a.
20. Common interosseous a.
21. Radial a.

Nerves (4)

22. Subscapular n
23. Ulnar nerve
24. Radial nerve on lateral side
25. Axillary nerve on lateral side

Muscle Action based on origin/insertion

26. What is the action of this muscle on the shoulder joint?
    Tag: lateral head of triceps brachii m
    Answer: No action on shoulder joint
27. What is the action of the muscles that insert here?
    Tag: accessory carpal bone
    Answer: flex carpal joints

Fixation/Synergist

28. Name one muscle that could act as a synergist with the tagged muscle's action on the shoulder joint
    Tag: Biceps Brachii m.
    Answer: supraspinatous muscle
29. Name a muscle that could be a fixation muscle to this muscles action on the carpal joints
    Tag: superficial digital flexor m.
    Answer: extensor carpi radialis m.

Nerve/Muscle Deficit

30. This nerve provides motor innervation to the muscle group that ___________ the carpal/IP joints. (action)
    Tag: median and ulnar nn where they are together
    Answer: flex

31. Damage to the nerve at this level would impair the dog's ability to ____________
    Tag: axillary nerve
    Answer: flex shoulder joint

Nerve functional/structural classification

32. Classify this nerve functionally: efferent afferent mixed
    Tag: suprascapular nerve
    Answer: mixed
33. Classify this nerve according to number of cytoplasmic processes of its neurons multipolar, pseudounipolar, both
    Tag: thoracodorsal nerve
    Answer: pseudounipolar and multipolar

Ligament Rupture

34. What ligament is damaged?
    Tag: second proximal interphalangeal axial collateral ligament on a left manus

Proximal/distal most actions of muscles

35. What is the most distal action of this muscle?
    Tag: extensor carpi radialis m
    Answer: extend carpal joints