Teaching and Learning Unit: Anatomy & Physiology

A Model for Studying the Relationship Between Form Function

Contributors:
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INTENDED COURSES:

Introductory Human Biology – 100/200 level
Introductory Vertebrate Anatomy & Physiology – 100/200 level

CHALLENGES:

- Make anatomy more interactive. Instruction in anatomy tends to be dry, relying heavily on rote memorization of large numbers of structures and associated functions.

- Many structures necessary to understand form-function relationships are not visible and are difficult to visualize.

- Students tend to resist instructors' attempts to link other subject areas, particularly physics and mathematics, in an effort to enhance the understanding of biological concepts.

- Student engagement in biological material often depends on the degree to which the subject can be made personally relevant. Students are most motivated to learn biological concepts that are associated with vertebrate disease and functional abnormality.

LEARNING GOALS & OBJECTIVES OF TLU:

During this instructional unit, students will:

1) explain the relationship between form and function for a whole muscle as well as an individual sarcomere.

2) further develop their independent learning skills by participating as part of a functional collaborative working group.

3) demonstrate higher-level thinking skills by applying comprehensive knowledge and conceptual understanding to novel situations. Students will build and describe multiple kinds of models that represent physical processes and patterns of motion.

TLU DESCRIPTION:

Class Meeting 1 (50 min) – Introduction of Topic

The goals of the first class meeting are to explore students' understanding about how skeletal muscles function. This will be done by administering an open-ended question at the beginning of class to probe for misconceptions about muscle function. Feedback will be displayed on an overhead so that students can comment and contribute to the discussion. It is assumed that students will arrive at class having read the appropriate assigned reading to prepare them for the class meeting.

Following the class discussion, students will then have time to interact with cooperative learning groups to further develop their explanations about muscle function using a specific muscle assigned to them by the instructor. The small group discussion provides an opportunity for students to ask questions of their peers, test their assumptions about muscle function, and further revise their explanations.

It is expected that a misconception or error made by many students, that muscles exert force by pushing or extending in addition to exerting force by pulling or shortening, will be revealed.

Class Meeting Plan and Timeline:

- Minutes 0-5: Think/Pair/Share to probe for misconceptions about muscle function.

At the beginning of class, students are presented with an open-ended question displayed on an overhead or powerpoint slide, "What do muscles do? How do they work?". Students work in pairs or small groups to discuss their ideas about how muscles function. Each student writes his/her own answer on paper.

- Minutes 5–15: Poll groups.

The instructor calls on groups to report-out and adds responses to a list displayed on overhead. Feedback from other groups is encouraged as the list is constructed.

- Minutes 15–20: Follow-up question to groups.

Groups are randomly assigned 1 of 3 different specific muscles that can be found on their own body, including: a) rectus abdominis, b) trapezius, and c) psoas major. Students are then posed the follow-up question: "How does this specific muscle function?".

Students apply principles/ideas presented on the class-generated list to the specific case of the muscle assigned to them. Students are encouraged to move around and actually ***use*** the muscles assigned to them to test their ideas and verify assumptions. Interactions among the group members help students generate ideas about how to revise the initial list. Students individually submit revised explanations on paper for grading at the end of the class period.

- (Optional) Minutes 20–30: 2nd report-out.

At least 1 group from each case reports the highlights of their discussion. The instructor revises the initial list according to student recommendations.

- Minutes 30–45: Mini-lecture on sliding filament model of muscle contraction.

- Minutes 45–50: Prepare students for lab activity.

Instructor prepares students with information necessary for a lab activity (Appendix 1) in which they will prepare their own version of a physical model to explain the sliding filament theory by modeling an individual sarcomere.

Assessments:

(Formative) Student feedback regarding list of ideas generated about muscle function informs instructor of misconceptions and barriers to understanding.

(Summative/Formative) Students construct explanations for muscle function on their own and revise them following peer instruction received during the small group discussion. This could be graded by the instructor according to any of a variety of rubrics, the simplest being a "+/c/-" method.

Lab Meeting (120 min)

The lab meeting is intended to serve as an opportunity for students to build models which explain muscle form and function, perform calculations to estimate force relationships, and develop and test predictions about how muscles will function given a variety of scenarios. During the lab, students will have access to physical models (one that they design and one which is provided) which can be manipulated to test their ideas about muscle function.

Formative assessment of students' thinking about muscle form and function is initially provided through whole-class feedback following their creation and demonstration of their original model. Students' ability to apply content and comprehensive knowledge to novel situations is then assessed through student responses on 2 worksheets which correspond to different lab activities. The activities are designed to address very different aspects of the form-function relationship: in one, students use mathematical relationships to describe physical processes, such as force generation within a muscle; in the second activity, students use physical models to predict patterns of motion that result from different muscle attachments.

Lab Meeting Plan and Timeline:

- Minutes 0-15: Students work with materials to design models (Appendix 1).

Students work with their permanent groups to assemble models of a sarcomere using materials provided in lab. Students "test" the model applying principles they learned from the previous day's lecture on the sliding filament model.

- Minutes 15-30: Groups demonstrate their models to class.

Depending on class size, all groups or a subset (e.g., 2) are called on to demonstrate their tentative models to the rest of the class. Students and instructor/s provide feedback and suggestions for improving those models.

- Minutes 30–60: Force calculation worksheet (Appendix 2).

Groups work to estimate the size of a muscle and corresponding force required to lift a specified weight. In order to answer the questions on the worksheet, students must work across several scales (from the individual sarcomere up to the whole muscle) and perform mathematical calculations to arrive at an estimate. This activity reinforces content and comprehension knowledge (e.g., terminology and hierarchical organization of associated structures) and well as students' ability to apply mathematics and physics concepts to a biological problem.

- Minutes 60–115: Lever worksheet (Appendix 3).

Groups work with equipment sets to manipulate components and test ideas to help them answer questions on the handout. Physical models are provided in lab which students are asked to use in order to make predictions and generalizations about muscle movement resulting from different attachments.

- Minutes 115–120: Conclude Lab.

At the conclusion of lab, students write their reflections about the lab activities in their lab notebook. The notebook "reflections" are considered an ordinary part of each lab session. Students are encouraged to address questions such as: What was the most significant/interesting thing you learned in this lab? What questions about [muscle function] do you still have that were not addressed in this lab period? What was the confusing/frustrating thing about today's lab? What was the thing that contributed most significantly to your learning in today's lab? Do you have suggestions for how to improve this lab in the future?

Before students leave the lab, the Case Study worksheet (Appendix 4) is distributed. The model for the jigsaw exercise is briefly described if students have not done this activity in previous class sessions. Students are expected to prepare answers to each of the cases in advance as they do not know which case group they will be assigned to.

Assessments:

(Formative) Model demonstrations and student feedback about models provides students and instructor and opportunity to explicitly address barriers to understanding.

(Formative/Summative) Worksheet based activities reinforce content knowledge and provide students opportunities to apply conceptual knowledge to novel problems. Worksheets are reviewed and graded by the instructor.

Class Meeting 2 (50 min) – Conclusion of unit/Problem-solving

In this class meeting, students use information gained through the previous class and lab activities to explain outcomes of several case studies. Cooperative learning groups are used in a jigsaw exercise to provide students an opportunity to ask questions of peers and validate their answers prior to the final assessment (quiz).

Class Meeting Plan and Timeline:

- Minutes 0–30: Jigsaw of Case Studies assigned in lab.

Minutes 0–15: "Case-groups". Students are randomly assigned to 1 of the 6 case-study groups. All students responsible for the same case work together to discuss their understanding of the problem, ask questions of one another, and approach a consensus agreement on the solution. Students determine how and who will be accountable for posting the final answer to an electronic forum (e.g., Blackboard) this is visible to all students.

Minutes 15–30: "Mixed-groups". Students regroup with original base groups. Each student takes 2-3 minutes to lead a mini-discussion debriefing the other group members about the consensus opinion of their case-group.

- Minutes 30–50: Summative Quiz (Appendix 5).

Students take a short quiz addresses constituent elements of sliding-filament model (comprehension) as well as application of those concepts to whole muscle function.

Assessments:

(Individual Accountability) Students individually post answers for each of the case studies after class. The instructor provides feedback on quality of answers (e.g., +/0

(Group Accountability) Students working together in case-groups post their version of a "correct answer" for the case – visible to all students. Groups are accountable to the rest of class for providing the most accurate answer for their case problem.

(Summative, Individual) The quiz (Appendix 5) closes the unit on form and function. Questions ask students to make predictions about muscle action and justify with an appropriate explanation. Students are also asked to explain the sliding-filament model as it applies to overall muscle function.

ASSESSMENT OF LEARNING OBJECTIVES:

GOALS	ASSESSMENT
At the end of this instructional unit, students will explain the relationship between form and function for a whole muscle as well as an individual sarcomere.	Students have multiple opportunities in lecture and lab to develop explanations, receive formative feedback, and revise their explanations prior to final assessment on a quiz.
Develop independent learning skills by participating as part of a functional collaborative working group.	Groups are integral in both lecture and lab for the initial introductory exercise, lab activities, and jigsaw.
Demonstrate higher-level thinking skills by applying comprehensive knowledge and conceptual understanding to novel situations by building multiple kinds of models that represent the physical processes and patterns of motion.	Case studies, worksheets, and quiz questions require students to apply concepts of form and function to a variety of situations. Students analyze results, compare results for alternative scenarios, and make predictions.

APPENDIX 1: Sliding Filament Exercise

Each group will receive a kit that includes the following:

Cardboard sheets	Pipecleaner
Velcro	Styrofoam "noodles"
Tape	PVC piping of varying diameters
Glue	Markers
Copper wire	Scissors

Using some or all of the materials in your kit (as well as any you choose to bring with you), your group will construct a functional sarcomere. Be sure to distinguish thick from thin filaments. When all models are constructed, several groups will be chosen to demonstrate how their sarcomere works in front of the class at the beginning of lab.

APPENDIX 2: Going from Tiny to Big

You have learned that the smallest functional unit in a vertebrate skeletal muscle is the sarcomere. Within the sarcomere, the actin/myosin crossbridges are the force generators for the muscle. In this exercise, our ultimate goal will be to determine the necessary diameter of a particular muscle needed to be to generate a particular amount of force. (Based on "Muscles as Engines" by C.J. Pennycuick: Newton Rules Biology: A Physical Approach to Biological Problems, Oxford University Press, 1992)

Assumptions:

A sarcomere is about 2.5 microns in length.
Each thick filament in a sarcomere has about 100 active crossbridges.
A single crossbridge can generate about 5 picoNewtons of force.
There are about 5.7×10^{14} thick filaments in each square meter of cross sectional area in a skeletal muscle.
The acceleration due to gravity is $9.8\ m/s^2$.

Questions:

1. Estimate the diameter of a bicep muscle necessary to hold a 20 kg weight so that gravity will not pull it down. **Hint:** You might want to begin with an estimate of the total force you need the muscle to generate and the total force that can be generated by one thick filament within a sarcomere. Recall that the unit of force is a Newton (1N = mass x acceleration = force required to accelerate 1 kg at 1 m/s^2).

ANS: The muscle must generate 20 kg x 9.8 m/s^2 = 196 N of force.
The force that can be generated by one thick filament is 100 crossbridges x 5 pN per crossbridge = 500 pN.
The cross sectional force of the muscle is 5.7×10^{14} thick filaments per m^2 x 500 pN per thick filament = $2.85 \times 10^5\ N/m^2$.
To hold the weight, one needs 196 N / $2.85 \times 10^5\ N/m^2 = 6.88 \times 10^{-4}\ m^2$.
This may make more sense in square centimeters:
$6.88 \times 10^{-4}\ m^2 \times (100\ cm)^2/m^2 = 6.88 \times 10^{-4} \times 10^4\ cm^2 = 6.88\ cm^2$.

2. How does your result compare to the actual size of your own bicep? What are some of the flaws with this estimation approach? How could you improve this estimate? What other information do you need?

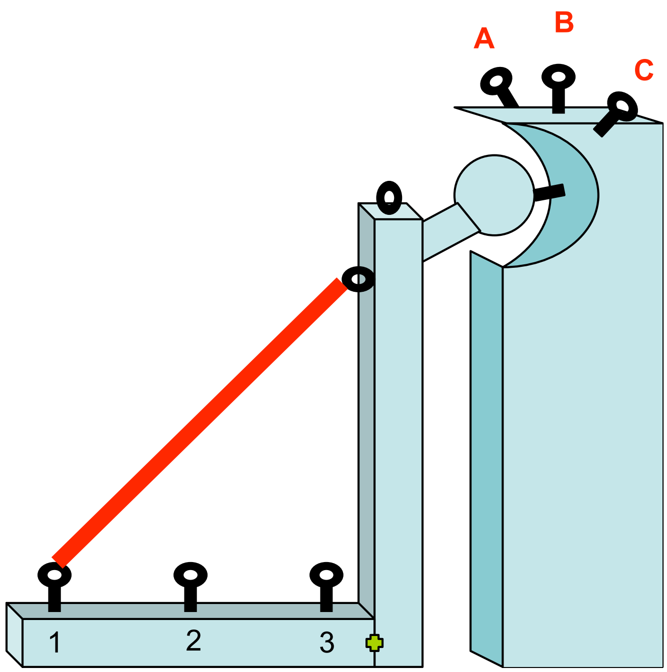
ANS: One can estimate the cross sectional area of a bicep as about 5 cm by 3 cm = 15 cm^2.

3. How would this calculation change if you wanted to lift the weight rather than just opposing gravity?

4. What conclusions can you draw about muscle function based on these calculations?

5. Imagine other muscles found in your hand and arm. Make predictions about the sizes and shapes of those muscles, justifying your answers based on your knowledge of the movements those muscles control.

APPENDIX 3: Lever Worksheet



1. Attach the distal end of the band to hook number 3. Pull on it. What action does this produce?

2. Which end would be the tendon of origin in this model? The tendon of insertion?

3. Now attach the band to hook number 1 and pull again. Compare this result to your answer to question #1. Explain any differences you observe.

4. Are the muscles in our arm attached more like the example in question #1 or question #3? Generalize this model to your arm muscles.

5. Imagine two different arms. In one of the arms, the muscles are attached to number 1 hooks; in the other, they are attached to number 3 hooks. Describe the appearance of each of these arms. Would they look different? How? Predict how this would affect movement of the arm.

6. Now, attach the 5 kg weight to the "hand" of the model. Is it harder to shorten the "muscle" band when it is attached to hook 1 or hook 3? Formulate a hypothesis about the relationship between tendon "insertion" and the amount of force needed to shorten muscles.

7. Looking at your answers for questions 5 and 6, what might be the advantages of having muscles attached more proximally?

8. Now, let's focus on the "shoulder." Attach the band to hook B. What action does this produce?

9. Now attach the band to hook A. Compare this result to the result from question #8. Explain why the results were different.

10. Predict what would happen if you attach the band to hook C. Justify your prediction in complete sentences. After writing down your prediction, test it on the model. Evaluate your results; if necessary, revise your hypothesis.

11. Now look at the picture of in your book of the deltoid muscle and read the description of its actions. Relate your answers from questions 8-10 to the deltoid muscle. Apply this same reasoning to three other muscles that you find in your book.

APPENDIX 4: Case Studies

Case study 1. An active adult male, age 28, enters the clinic complaining of pain in his anterior leg. He was apparently hurt during a soccer game. As his foot was dorsiflexed to kick the ball, another player fell and jammed the patient's foot further in dorsiflexion.

When asked to cross the room, the patient walks with a "steppage gait": he walks with an exaggerated flexion of the right hip and knee to prevent his right toes from catching on the ground during swing phase. As the foot swings through it is uncontrolled and slaps the ground.

A neurological examination shows no problems. The problem appears to be muscular. Which muscle or muscles do you think are involved? Why?

ANS: Muscles that dorsiflex the foot, such as tibialis anterior, were damaged during the soccer accident. "Steppage gait" is characteristic of a syndrome called foot drop. Often, the causes of foot drop are neurological, but they can also be muscular. During gait, as we swing our foot through to plant it on the ground in front of us, we dorsiflex our feet so that our toes do not scrape along the ground. The exaggerated flexion of the right hip and knee of "steppage gait" accomplish the same goal. The attachment of tibialis anterior was probably torn or damaged when the patient's foot was forced into hyper-dorsiflexion by the fallen player.

Case Study 2. Many years ago, when a woman was treated for breast cancer, it was common to remove the pectoralis major muscle along with the affected breast. a) Which actions would be compromised by the removal of pectoralis major?

ANS: Adduction, flexion, and medial rotation of the arm.

b) After the surgery, the patient works with a physical therapist to strengthen certain muscles. Which muscles would the patient want to strengthen to compensate for the loss of her pectoralis major?

ANS: Synergists of pectoralis major.

Other flexors of arm: coracobrachialis, anterior deltoid

Other adductors of arm: infraspinatus, teres minor, teres major, latissimus dorsi, subscapularis, coracobrachialis.

Other medial rotators fo the arm: teres major, latissiumus dorsi, subscapularis

Case Study 3.   After the gun went off for the 100 meter race, Ben Johnson, who had heretofore been happy and healthy (despite his steroid use), took two steps and fell to the ground in pain.   The athletic doctor could not be found, so coaches helped him to the sidelines. Ben could not walk, because he could not flex his left leg at the knee. A bruise was noticed at the back of his left thigh, and as they waited for the doctor to arrive, the bruises

spread down the back of his leg past his knees. His leg also began to swell making it difficult to move his leg.

What muscle or muscles do you think were torn? Why? What kinds of stretches could Ben have done to prevent this injury?

ANS: Ben injured one or more of his hamstring muscles: biceps femoris, semimembranosus, and semitendinosus. This is a common injury during sports that requires intense, fast acceleration such as sprinting. The bruising in the back of the thigh is due to bleeding from the torn muscle tissue. The swelling is a result of the bleeding. Stretches that warm up the back of the leg, where **extension** of the knee is involved, may have prevented this injury.

Case Study 4: Athlete's injury
A pole vaulter injures himself during a fall and ruptured the posterior head of the deltoid. He experiences severe pain and swelling in the dorso-cranial aspect of his shoulder. Neurological exam was normal. Which actions would be compromised by this injury? Explain.

ANS: abduction, external rotation

b) After recovery, the patient worked with a physical therapist to strengthen certain muscles. Which muscles would the patient want to strengthen to compensate for the decreased strength in the posterior head of the deltoid?

ANS: supraspinatus, infraspinatus, teres minor

Case Study 5: Ice skater's woe
An ice skater arrives at the ER with a painful ankle. She informs the doctor that she twisted her ankle while skating. For each muscle that stabilizes the ankle, design a protocol of physical manipulation that will establish whether it is injured.

ANS:
Anterior tibialis: flexion of foot
Gastrocnemius & soleus: extension of foot
Peroneus (brevis & longus)

Case study 6: Weekend warrior
A 39 year old male ruptured his distal biceps brachii when he took a hard fall while snowboarding. He heard an audible popping sound and experienced intense pain. Which actions would be compromised if the rupture were not repaired. Surgical repair resulted in normal elbow flexion, but decreased supination. Analyze the anatomical problem that resulted in the patient flexing his elbow normally but no supination.

ANS: The surgeon attached torn biceps too laterally.

APPENDIX 5.

15 minute final quiz (summative assessment)

1. Examine the following diagram. Predict the action(s) of the muscle indicated by the arrow in the diagram. Briefly justify your reasoning.

2. When asked "How does the chest muscle (pectoralis major) of a pigeon work?", a student answered:

The muscle functions to move a wing up and down by pulling the wing down and then pushing it up. The muscle contracts when the actin and myosin filaments shorten. The shortening of the filaments then causes the entire muscle to be shorter, and the wing comes down. All the filaments extend again, the muscle gets longer, and the wing is pushed up.

Critique this statement. Write a better answer making any revisions you think are necessary.

Grading Rubric
Form and function teaching unit

For each evaluation point, student answers will be ranked as
E=excellent, G=good, F=fair, U=unsatisfactory
Short comments will be given to clarify the reasoning for the ranking.

Question 1. Examine the following diagram. Predict the action(s) of the muscle indicated by the arrow in the diagram. Briefly justify your reasoning.

1a. Did the student correctly predict the actions of the muscle?

1b. Did the student's justification include a clear and correct description of the lever action of the joint?

1c. Did the student clearly relate the form of the muscle angle and joint angle to muscle action?

Question 2. When asked "How does the chest muscle of a pigeon work?", a student answered:

The muscle functions to move the wings up and down by pulling the wing down and then pushing it up. The muscle contracts when the actin and myosin filaments shorten. The shortening of the filaments then causes the entire muscle to be shorter, and the wing comes down. All the filaments extend again, the muscle gets longer, and the wing is pushed up.

Critique this statement. Make any revisions that you think are necessary.

2a. Did the student identify the push/pull misconception?

2b. Did the student identify the filaments shorten rather than slide misconception?

2c. Did the student point out the aspects of the statement that were correct?

2d. Did the student write a clear, complete, and concise revised answer?

2e. Did the revised answer relate sarcomere level structure and function to whole muscle level structure and function?