In the lesson sequence described below, students collaboratively develop and build a physical model of an arm and then use it to understand deeply the role of muscles, ligaments, and tendons in movement. The described instructional approach also promotes creativity, effective communication, collaboration, problem-solving, and nature of science understanding—all important aspects of science instruction and then scaffolding appropriately, among other representations of the phenomenon, assist students in grasping difficult concepts (Olson, 2008). This means that more abstract representations (e.g., readings), which are generally more difficult for students to understand, should follow relevant concrete experiences (e.g., hands-on experiences). However, effective teacher questioning must be implemented to help students make accurate sense and connections between the variety of representations.

Employing meaningful concrete experiences poses numerous challenges when teaching human anatomy. Human cadavers are largely impractical for secondary school science courses, and students’ inadequate prior knowledge interferes with accurate sense-making when animal dissection is introduced too soon. The following lesson sequence provides a mentally engaging, concrete, model-building experience that establishes a foundation for developing and understanding a wide range of anatomical and physiological concepts and general biological principles (e.g., form and function) that in turn form a strong foundation for scaffolding to other, more complex representations.

This inquiry approach should also be leveraged to address features of scientific models, an important nature of science (NOS) issue appearing in the Next Generation Science Standards (NGSS Lead States, 2013). Such instruction is particularly important with scientific models because many students hold the misconception that they are simply replicas of the target items (Grosslight et al., 1991; Ryan & Aikenhead, 1992) and are unaware of the role models play in furthering research (Grosslight et al., 1991; Grünkorn et al., 2014). This lesson sequence also embeds questions to guide overt discussions with students about many of the important features of scientific models appearing in Table 1.
Table 1. Features of scientific models (Van Der Valk et al., 2007).

1. A model is made for a specific purpose and is associated with a target.
2. A model allows researchers to gain information about the target that is otherwise not easily accessible.
3a. Models are analogous in some ways with their targets.
3b. The similarities between models and targets allow researchers to make and test predictions.
4. A model is not the exact same as its target, which makes the model more amenable for conducting research.
5. Models must strike a balance between similarities (3a) and differences (4) with the target.
6. Since a model cannot be the same as its target (4), creativity is needed in making interpretations, simplifying, and otherwise developing the model.
7. A target may have more than one consensus model associated with it.
8. Models can be iteratively modified during research.

Preparing for the Activity

Prior to the lesson, the teacher must build a model of an arm (Figure 1). While a range of materials can work, the supplies depicted in Figure 2 are widely available for minimal cost and generally satisfy the requests of students during their own model-building. Place a shirt or sweatshirt sleeve over the model so that students can observe the arm moving but not the musculoskeletal mechanism.

Prior to beginning the full lesson sequence, the teacher should set aside the last 15 minutes of a class period to introduce the project. Again, the teacher-built model should be obscured by placing a sweatshirt over it, and the teacher should merely show students how the lower arm can be drawn upwards (i.e., flexion). The teacher should then state that the objective of the activity is to build a model of an arm that is capable of creating the same motion as the one presented by the teacher. Students should then work in pairs to draw at least two models of an arm that they could build. In order to promote creativity and independence in students, the teacher should only show two of the pieces of wood from Figure 2 but otherwise require that students determine what additional supplies they would need to construct their models. Students should therefore include a list of required supplies with their sketches and a brief rationale for why they would need each requested component. Having students develop at least two models is desirable not only because it challenges them to think of alternative ideas that could account for the motion of the arm, but the plurality of designs also increases the likelihood that at least one option will rely on materials that can feasibly be procured. Typically, the types of materials shown in Figure 2 will satisfy the needs of most groups, with unique requests evaluated for safety and appropriateness.

Day 1: Model Construction

The day of model construction, class should be held in a location with sufficient space for students to safely build the models. Lab spaces are often adequate, otherwise outdoor spaces can be utilized, or industrial arts rooms work well if they are available. The teacher should begin by emphasizing safety. Students must wear safety goggles at all times throughout the construction process. Safe and appropriate use of each tool must also be emphasized, particularly if hammers, drills, or staple guns are used. Students often do not consider what might happen to the lab bench beneath the piece of wood they are hammering nails into, and therefore they must be taught to place scrap wood beneath the model they are constructing. Arm models should then only be extended when others are far enough away to avoid eye injuries if the punch balloon, cord, or attachment were to fail. To assist students in thinking through safety issues, ask questions that draw students’ attention to concerns related to balloons snapping, or the low chance of improperly secured nails, screws, or staples being propelled across the room (e.g., What might happen to the nail when you open the arm and the balloon pulls on it? Given this possibility, where must you and others not be when the spring/balloon is extended?).

During the building and testing of models, constantly circulate among students to ensure safety and to ask questions that promote thinking and conceptual understanding, and assist those who may be struggling. Pay particular attention to groups who had previously...
Figure 2. Typical construction materials needed for this activity: A.) Scrap wood from the shop class was generally sufficient for the boards. B.) Small hinges. C.) Paracord, or other strong, thin rope. D.) Of the tools shown, only screwdrivers are generally absolutely necessary. Power drills and staple guns provide convenience, but they do pose potential safety hazards and therefore require careful safety instruction and supervision. E.) Fastening materials to connect the rope to the boards, such as screws, nails, hooks, eyelets, or even zip-ties. F.) Punch balloons are particularly effective for the model as they are generally durable, provide adequate force for flexion, come with a premade attachment point for the cord on one end, and resemble the shape of the biceps muscle. Large rubber bands and springs can also be used.

submitted flawed model designs (e.g., some students place the insertion point of the biceps tendon on the board representing the humerus [Figure 1, location C], rendering the punch balloon useless). To promote mental engagement and understanding, ask probing questions such as:

- What is the purpose of (model component)?
- What makes (model component) well-suited to accomplish that purpose?
- How would your model function differently without (model component)?
- What problems might occur if you attach your balloon to that location? How might you rectify that?

These kinds of questions are critical to make the thinking of all students visible, quickly identify and address misconceptions, and provide a concrete foundation for concept development during the class discussion following the activity. After each group has completed assembly of their arm model, they must video-record its movement (i.e., a clip no longer than a few seconds showing the profile of the arm as it closes) using a cellphone or provided camera and show the teacher their work. The students should then carefully disassemble the arm to minimize damage to the parts and return all of the components to the appropriate places for the next class. While waiting for other groups to finish, each student must provide written responses to the following prompts:

- Draw a sketch of your final model and explain the function of each component you used.
- Describe how successful your model was (i.e., how similar it was to the motion of an arm closing).
- How could your model be improved?
- Identify two ways your model would most likely have broken if you had used it extensively, and how the failure would impact arm motion.

The first three prompts are aimed at having students reflect on the activity, while the fourth prompt sets the stage for upcoming discussions about the need for tendons and various injuries to the arm (e.g., ligament damage).

**Day 2: Concept Development**

Begin class by having several groups with disparate models share their videos with the rest of the class and briefly explain their models. Have students present and explain their ideas, respond to questions from others, and defend or alter their thinking. Include other practices that reflect those of an authentic scientific community. After sharing models, reasoning, and evidence, overtly draw students’ attention to another important scientific practice—model-building. Since the first-author addressed the role of model-building throughout the school year, revisiting the NOS issues appearing in Table 2 took little time, but the questions can also be used at any time in the school year to draw students’ attention to important features of scientific models.

The prior learning experiences set the stage for presenting anatomically accurate models of the human arm. Terminology such as “biceps muscle, tendons, and ligaments” should now be introduced along with the role of each in causing flexion to occur. The prior concrete experiences and more accurate understandings developed in those experiences are here leveraged to promote deep and robust understanding of the arm that is then applied to other parts of the musculoskeletal system. Use of scaffolding questions is essential during this portion of the lesson to fully take advantage of the prior concrete experiences. For example, a common student model simply connects the punch balloon (i.e., muscle) directly to the wood. Since the balloon easily tears, that model and student video provide the concrete foundation to ask, “How durable is the direct connection of the balloon to the wood?” and “How could we connect the balloon to the wood in a manner that would reduce the chance of it ripping?” The crucial point is developing a robust understanding of the role tendons play in connecting muscles to bones, and this understanding is far more easily comprehended by students after having had the concrete experience of creating and building their arm models. The teacher-built model should be revealed at this time to provide a tangible example of a method of connecting balloons to the wood that is analogous to tendons.

After this initial concept development discussion, have students complete the “Making an Arm Work” task, which appears in the Supplemental Material with the online version of this article. On the worksheet, students a) state the function of bones, ligaments, tendons, muscles, and the joint; b) identify the analogous components in their model; and c) address important features of scientific models. Importantly, students must explain the ways in which the model components are analogous to the parts of the human arm. Since some students’ models may not have analogous parts (e.g., nothing
The students' models share most of the important features of scientific models. (Teachers can modify the worksheet for students pictured what they were going to build, they were forming mental models. The sketches that students made would be considered models, and when students pictured what they were going to build, they were forming mental models. Scientific models are not simply replicas of the targeted phenomena but rather are built to help explain and make predictions about it. Simply copying the phenomena being investigated would do neither and be of little explanatory use (Table 1, Feature 4).

| Potential NOS Questions about Scientific Models | Corresponding Accurate Conceptions about Models |
|-------------------------------------------------|-----------------------------------------------|
| Why would describing scientific models as “copies” of the targeted phenomenon be inaccurate? | Scientific models are not simply replicas of the targeted phenomena but rather are built to help explain and make predictions about it. Simply copying the phenomena being investigated would do neither and be of little explanatory use (Table 1, Feature 4). |
| In what ways are the “arms” scientific models? | The students’ models share most of the important features of scientific models (Table 1). For example, in subsequent lessons, the models assist students in making predictions about arms (e.g., What will happen when a tendon breaks?), which is consistent with Feature 3a. |
| In what ways were your model-building and models different from actual scientific models? | Scientists would undoubtedly spend more time studying human arms, use more sophisticated methods (e.g., dissections) to do so, devote significantly more time constructing their models, have access to more advanced materials and equipment, create more precise models, and ask more specific questions about the arm. |
| If we were to continue to develop your scientific models of the arm, how might you improve them and make them more precise? | Models could be improved by further testing and comparison to actual movement of arms. Materials which more closely approximate actual parts of the human arm could also be utilized. Competing models could be assessed by comparing how well they account for the functioning of actual arms and the accuracy of their predictions. |
| Scientific models are not the actual targeted phenomenon; therefore, they have strengths and weaknesses. What are some of these strengths and weaknesses? | This question can be used to discuss either the pros and cons of the types of representations used (e.g., physical models versus drawn) or the manner in which specific models that had been built differentially captured certain aspects of how the arm works (e.g., models built with hinges more closely approximate the motion of the elbow than groups which opt to use tape or string to join the boards). |
| What would be the pros and cons of adding more and more details to our model to make it more realistic? | Pros: With each addition, the model could function more like a human arm really does. Cons: Each addition would make the model more complex. |
| What else did you make yesterday that could be considered a scientific model? | The sketches that students made would be considered models, and when students pictured what they were going to build, they were forming mental models. |

A logical, and important, next step in the lesson sequence is to move to antagonistic muscle pairs. To do so, the teacher should end the second day by stating, “We have now explained how we lift the forearm, but how can we extend the forearm? Come to class tomorrow with a written idea for how we could expand upon our models to accomplish such a motion.”

**Day 3 and Beyond: A Plethora of Possible Connections**

Begin by again raising the question that ended the previous day. Have students modify the classroom arm model to include a second punch balloon with ropes on the back of the arm while once again maintaining appropriate safety considerations. Review what each component does as the modifications are being made (e.g., What is the advantage of using ropes to attach the balloon?). Once the model has been modified to include a representation of the triceps, ask, “With both the raising and extending of the forearm, what are the muscles doing?” This, of course, draws students’ thinking and understanding to the important point that muscles only contract. That concept, along with the models that students have created, provides a firm foundation for developing the understanding that muscles are found in antagonistic pairs throughout the body. Drive this point home by having students feel the tension in the contracting muscle and relaxed antagonistic muscle while using a dumbbell weight to do a biceps curl and triceps extension.

This sturdy fundamental understanding of musculoskeletal systems provides the foundation for addressing a wide range of anatomical and physiological content, such as analytical terms of motion, exploration of specific antagonistic muscle pairs within the body, ligament and tendon damage, and origin and insertion points. In each case, the teacher uses the prior experiences in this lesson to assist students in understanding more complex and difficult ideas.
For example, when teaching about tendon damage, the teacher can show the model, and before cutting one of the ropes on it, can ask questions such as, “What do you think might happen if this rope were damaged or broke? What would the balloon (i.e., muscle) do? How might this look on your body?” During dissections, students are in a far better position to accurately observe and understand what they see. For students who become confused during dissections, the arm model provides a more concrete and familiar example to assist them.

Effectively engaging students in concrete experiences takes time, which is a precious commodity when teachers are often expected to address a dizzying and often overbearing array of standards. However, students lacking these experiences too often do not truly understand, retain, and accurately apply what is taught. Thus, common traditional instructional practices waste teachers’ and students’ time because little (and sometimes nothing) is gained. The first-author implemented the activity described here, and students appeared to understand and remember more deeply the structure and function of the musculoskeletal system, as evidenced by problem-solving assessments, proficiency with dissections, and knowledge displayed during routine conversations with students. Students also frequently reported the activity as being memorable, enjoyable, and helpful for their learning. Implementing the arm model as presented in this article truly established a foundation for the entire unit, and improved students’ understanding of scientific models and their role in scientific practices—an incredible return on the investment.

Supplemental Material

Student worksheet: Making an Arm Work

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