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Lesson title: How Does the Elbow Work: A Lesson in Levers

Grade Level: It is most suitable for high school students who are advanced in Biology with some Physics background or for Physics students who are learning about levers.
I used this lesson in an Anatomy and Physiology class that was composed of juniors and seniors who had taken introductory biology.

Overview: There are three basic categories of levers that exist in the human body. These lever classes differ in how they function mechanically. Most people assume that the body would use levers in the most mechanically advantageous manner. This lesson examines third class levers in the body and demonstrates that in fact there is a consistent pattern of reducing the mechanical advantage of third class levers in the body. This is not maladaptive. A reduction in the mechanical advantage of a third class lever maximizes the angular velocity and displacement of the moving end of the lever.
The role of third class levers in the body is examined by modeling the elbow. The elbow consists of the articulation between three bones: the humerus, the radius, and the ulna. When you bring your hand closer to your shoulder, this is a movement known as flexion. Flexion at the elbow is caused primarily by the biceps brachii as long as your palm is facing up. So in this example the elbow acts as the fulcrum of the lever and the biceps acts as the force being applied to the lever. The elbow is a type of third class lever. Other examples of a third class levers are a crane and a drawbridge.

To understand how the elbow works we need to know a few basic principles of levers.

> Levers try to move a weight through space. The weight being moved is known as the resistance. In the elbow example above, think of doing a biceps curl with a 50lb. barbell in your hand. The barbell represents the resistance. The force we apply to a lever is known as the effort. When doing a biceps curl, the biceps applies the effort. We can measure how efficient a lever is by computing its mechanical advantage. The mechanical advantage is a ratio of the effort arm/ resistance arm. Each of the arms is a distance measured from the fulcrum. The effort arm is the distance from the fulcrum to the point where the effort is applied. In our elbow example, the effort arm is the distance from the elbow to the point where the biceps is pulling on the forearm, known as the biceps insertion. The resistance arm is the distance from the fulcrum to the point where the resistance is applied, so in our elbow example the resistance arm is the distance from the elbow to the hand where the barbell is being held.

Before we examine a third class lever we need to understand how it differs from first and second class levers. Now that we know about mechanical advantage we can uncover the differences.

> A first class lever is like a seesaw. In first class levers the fulcrum is situated between the effort and resistance forces. For a 1st class the mechanical advantage

(MA) would be exactly one if the fulcrum is exactly in the middle of the two forces. If the fulcrum is located near the resistance force, then the MA is greater than one. If it is closer to the effort force then it is less than one.
A second class lever is like a wheelbarrow. In second class levers the fulcrum is not between the effort and resistance forces. In a wheelbarrow the wheel is the fulcrum. The effort force is applied to the handles of the wheelbarrow and the resistance is between the effort and the fulcrum. In the wheelbarrow example the MA is greater than 1. To make a wheelbarrow more efficient (higher MA) we would make the handles of the wheelbarrow longer and thus increase the effort arm. In a second class lever the effort arm is always longer than the resistance arm.
A third class lever is like a drawbridge or a crane. In a third class lever the fulcrum is not in the middle. Unlike second class levers, in 3rd class levers the resistance arm is always shorter than the effort arm, so the MA is always less than one. To maximize the MA you would put the effort force as close to the resistance force as possible and thus make the MA as large as possible.

Most of the movable joints in the body act as fulcrums of third class levers. Let's examine the elbow. The effort is applied by the biceps at its insertion on the bicipital tuberosity which is located very near to the elbow. The resistance is in the hand. So the resistance arm is much longer than the effort arm and the fulcrum is not in the middle.

The elbow is a third class lever.

To maximize the efficiency (mechanical advantage) of the elbow we would move the biceps insertion as close to the resistance as possible. This is not the way the body is "designed". The biceps insertion is close to the elbow, making the MA as small as possible. Why would the body do this? There is an inversion relationships between MA and angular displacement. The more mechanical advantageous a third class lever is, the small the amount of angular displacement that is possible at even given force. Moving the effort force close to the elbow allows for a greater range of angular displacement at any given force. This means that angular velocity is also maximized. The elbow is designed to maximize angular displacement and velocity to mechanical efficiency.