Teacher Guide: Pulley Lab

Learning Objectives
Students will …
- Understand what a pulley is and what it does.
- Observe that adding pulleys to a system reduces the input force needed to lift a load.
- Calculate the mechanical advantage of a pulley system.
- Calculate the input work and output work for a system of pulleys.
- Explain how an ideal pulley system demonstrates conservation of energy.
- Explore how friction reduces the effectiveness of a pulley system. (Extension)

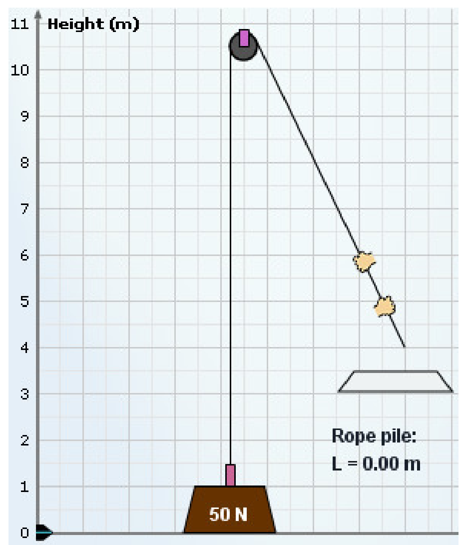
Vocabulary
block and tackle, conservation of energy, efficiency, friction, input force, load, mechanical advantage, output force, pulley, pulley system, simple machine, work

Lesson Overview
In the *Pulley Lab* Gizmo™, students can lift a load using a pulley or pulley system with up to three fixed and three moveable pulleys. The weight of the load and the efficiency of the pulley system can be varied.

Note: This Gizmo covers similar topics to the *Pulleys* Gizmo, but at a more advanced level.

The Student Exploration sheet contains two activities and an extension:

- Activity A – Students calculate the mechanical advantage of each pulley system.
- Activity B – Students calculate the work done by a pulley system.
- Extension – Students explore pulley systems with less than 100% efficiency.



How much force is needed to lift the weight?

Suggested Lesson Sequence

1. **Pre-Gizmo activity: Simple machines** (15 – 30 minutes)
   Pulleys are examples of simple machines. In many simple machines, mechanical advantage is created by increasing the distance over which the input force is applied. For example, a first-class lever produces a mechanical advantage when the load is placed near the fulcrum and the effort is applied far from the fulcrum. The effort is much less than the load but must be applied over a large distance to raise the load a little bit.

   Bring in examples of simple machines (levers, inclined planes, wedges, screws, pulleys, and wheel and axles) to demonstrate this principle. With each machine, guide students to see that a small effort force is applied over a large distance to move the load.

2. **Prior to using the Gizmo** (10 – 15 minutes)
Before students are at the computers, pass out the Student Exploration sheets and ask students to complete the Prior Knowledge Questions. Discuss student answers as a class, but do not provide correct answers at this point. Afterwards, if possible, use a projector to introduce the Gizmo and demonstrate its basic operations. Demonstrate how to take a screenshot and paste the image into a blank document.

3. **Gizmo activities** (15 – 20 minutes per activity)
Assign students to computers. Students can work individually or in small groups. Ask students to work through the activities in the Student Exploration using the Gizmo. Alternatively, you can use a projector and do the Exploration as a teacher-led activity.

4. **Discussion questions** (15 – 30 minutes)
As students are working or just after they are done, discuss the following questions:
   - How does adding pulleys affect the effort needed to lift an object?
   - How does the number of pulleys in a system relate to the mechanical advantage of the system? (Assuming an equal number of fixed and moveable pulleys, mechanical advantage is equal to the number of pulleys.)
   - How does adding pulleys affect the amount of rope that needs to be pulled to lift an object?
   - For an ideal pulley system (100% efficient), what is the relationship between the input work and output work? How does this demonstrate conservation of energy?

5. **Follow-up activity: Pulley experiments** (45 – 90 minutes)
Have your students design and build pulley systems capable of lifting small loads. Pulleys can be purchased from a hardware store or in kits from educational catalogs. A low-budget alternative is to use paperclips for the pulleys and fishing line for rope. Use a spring scale to measure the input force required to lift an object and to measure the weight of the object.

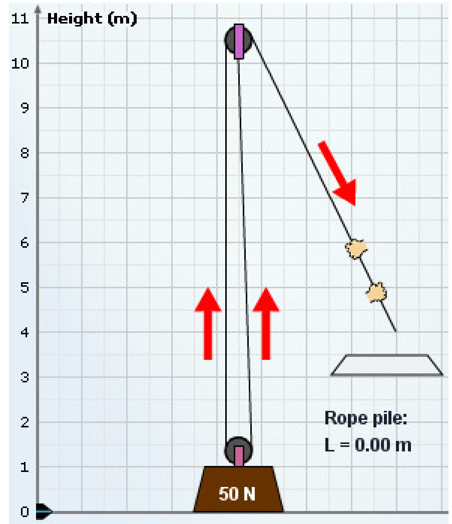
   Build a variety of pulley systems (students can design their own) and calculate the mechanical advantage and efficiency of each system. If you have enough available pulleys, divide the class into 4–5 teams and have a contest to see which team can build a pulley system that can lift a load using the least amount of force.

Scientific Background

Six types of simple machine are commonly studied: inclined planes, wedges, screws, levers, pulleys, and wheel and axles. Often, simple machines are used to amplify the input force (or *effort force*) exerted by a user. This is done by changing the distance over which the input force is applied. A simple machine converts a small input force exerted over a large distance to a large output force exerted over a small distance. The *mechanical advantage* of a machine is equal to the ratio of the output force (F_{out}) to the input force (F_{in}): $MA = F_{out} \div F_{in}$.

A pulley is a wheel with a groove for a rope or cable. A *fixed pulley* is attached to a frame while a *moveable pulley* is attached to the object that is being lifted, or the *load*. A single fixed pulley provides no mechanical advantage but changes the direction over which the force is applied. It is often easier to pull down on a rope (using your body weight) than to pull up on an object.

Now consider a pulley system with one moveable pulley. Notice that there are *two* segments of the rope that are pulling up on the load. An input force is applied equally to the entire length of the rope (red arrows), which means that the output force on the load is twice as great as the input force on the rope. If the load is 50 newtons, it will require just over 25 newtons of effort force to lift the load. In general, each additional moveable pulley adds two rope segments and increases the mechanical advantage by 2.



This mechanical advantage doesn't happen "for free," however. To lift the load to a height of 10 meters, 20 meters of rope needs to be pulled. In general, an ideal pulley system (100% efficiency) will obey the following rule:

$$F_{in} \cdot d_{in} = F_{out} \cdot d_{out}$$

Where d_{in} is the input distance and d_{out} is the output distance (or height of the load). *Work* is the product of force and distance, so the equation can be rewritten as work input equals work output. Because work is a form of energy, this satisfies the law of *conservation of energy*.

In reality, some input energy is lost to friction, thus the output work is always less than the input work. The *efficiency* of a simple machine is equal to the ratio of the output work to the input work, usually expressed as a percentage.

Historical Connection
Nobody knows who invented the pulley, but the first recorded use of a pulley system was by the Greek mathematician Archimedes (287–212 B.C.). After discovering the laws of pulleys and levers, Archimedes boasted to his friend King Hieron of Syracuse that he could use his simple machines to move any weight, no matter how large. Hieron asked for a demonstration and loaded a ship with cargo and sailors. Sure enough, Archimedes was able to move the ship by himself using his pulley system.

Selected Web Resources
Explanation of pulleys: http://www.howstuffworks.com/pulley.htm
Detailed explanation of pulleys: http://en.wikipedia.org/wiki/Pulley
Pulley lesson: http://www.tryengineering.org/lessons/pulleysandforce.pdf
Pulley labs: http://www.fifeschools.com/cjh/staff/laker/documents/pulleylab.pdf, http://teachingphysics.wordpress.com/2009/03/19/pulley-lab-mechanical-advantage/
Archimedes and pulleys: http://www.swe.org/iac/lp/pulley_03.html

Related Gizmos:
Pulleys: http://www.explorelearning.com/gizmo/id?643
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