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Lesson Focus

Lesson focuses on the concept of force and the use of pulleys to reduce required force.

Lesson Synopsis

The Pulleys and Force activity explores the concept of force and shows how pulleys are used in everyday life to make work easier. Students learn about different uses for pulleys, the impact of multiple pulleys, and identify pulley use in school and their community. Students test the ability to move weights using one, two, and four pulleys in a series.

Age Levels

8-11.

Objectives

- ◆ Learn about pulleys and pulley systems.
- ◆ Learn how using multiple pulleys can dramatically reduce required force.
- ◆ Learn how pulley systems are used in machines and impact everyday life.
- ◆ Learn about teamwork and problem solving in groups.



Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:

- ◆ pulleys
- ◆ force
- ◆ work reduction
- ◆ problem solving
- ◆ teamwork

Lesson Activities

Students learn how pulleys work, and explore how multiple pulleys used in sequence can reduce required force to move an object. Topics examined include force, pulleys, and problem solving. Students work in teams to design a pulley system to require the least amount of force to move a weight.

Pulleys and Force

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Resources/Materials

- ◆ Teacher Resource Documents (attached)
- ◆ Student Resource Sheet (attached)
- ◆ Student Worksheets (attached)

Alignment to Curriculum Frameworks

See attached curriculum alignment sheet.

Internet Connections

- ◆ TryEngineering (www.tryengineering.org)
- ◆ Wikipedia Pulleys (<https://en.wikipedia.org/wiki/Pulley>)

Recommended Reading

- ◆ Using Pulleys and Gears (Machines Inside Machines) (ISBN: 1410914453)
- ◆ New Way Things Work, by David Macaulay (ISBN: 0395938473)
- ◆ Moving Heavy Things, by Jan Adkins (ISBN: 0937822825)

Optional Writing Activity

- ◆ Write an essay or a paragraph describing how pulleys are used in a marina or shipyard.

Extension to Older Students

- ◆ Older students work in teams to develop a pulley system that would allow a student weighing 60 pounds to lift an adult that weighs 180 pounds or three times the student's weight.

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For Teachers: Teacher Resource

◆ **Lesson Goal**

Explore force by demonstrating how pulleys and pulley systems operate. Students compare the force needed to move an object using a single pulley and multiple pulley system, learn about pulley use in machines and everyday objects, and work in teams to create multiple pulley systems.

◆ **Lesson Objectives**

- ◆ Students learn about pulleys and pulley systems.
- ◆ Students learn how using multiple pulleys can dramatically reduce required force.
- ◆ Students learn how pulley systems are used in machines and impact everyday life.
- ◆ Students learn about teamwork and problem solving in groups.

◆ **Materials**

- ◆ Student Resource Sheet and Worksheet
- ◆ One set of materials for each group of students:
 - Household Twine
 - Two 2" or larger pulleys
 - Weight (either a small or 1 liter plastic water bottle filled with liquid or sand)

◆ **Procedure**

1. Show students the various Student Reference Sheets. These may be read in class or provided as reading material for the prior night's homework.
2. Divide students into groups of 3-4 students; provide one set of materials per group.
3. Show students the filled water container and ask them to develop a plan to lift the bottle using a single pulley.
4. Ask the students to build their system using the materials provided, so that it operates. Pulleys can be tied to door handles, drawer pulls, or other stable objects with twine, and twine may be used to run through the pulleys, and tied to the neck of the bottle.
5. Ask the students to observe the direction they are pulling (or exerting force) and how, when using one pulley, it is the opposite direction of the intended work (lifting the bottle).
6. Ask students to add another pulley to their team's system and determine how the addition of a second pulley impacts the amount of force needed to lift the bottle. Does it require less force to move the bottle?
7. Combine two student groups so that four pulleys are now available. Have the new, larger group design a new system for lifting the bottle using all four pulleys. The team should predict what will happen to the required force needed to lift the bottle.
8. Each student group presents their pulley system to the class and explains what worked and what didn't work in their design.

◆ **Time Needed**

One to two 45 minute sessions

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**For Teachers:
Teacher Resources**

◆ Single Pulley Set Up

The photo to the right shows a simple single pulley which could be used to lift a water bottle. Notice that the direction of force exerted to lift the bottle is the opposite of the motion of the bottle -- you pull down to lift the bottle up.

Step One: Tie one pulley to a door knob, drawer pull, or some fixed object that can withstand the weight of the water bottle.

Step Two: Tie a length of twine to the neck of the water bottle and thread through the pulley.

Step Three: Pull down on the twine and notice the amount of force needed to lift the water bottle. Observe that the direction of force (down) is the opposite of the resulting bottle movement (up).



◆ Two Pulley Set Up

Another option is to do the set up using two pulleys. This second pulley should reduce the amount of force needed to lift the water bottle by one half. Additional pulleys should further reduce the force needed. More information for research and students is available at Wikipedia Pulleys (<https://en.wikipedia.org/wiki/Pulley>).

Step One: Tie one pulley to a door knob, drawer pull, or some fixed object that can withstand the weight of the water bottle.

Step Two: Affix the neck of the water bottle with string to the second pulley.

Step Three: Tie string to the bottom of the top pulley. Wind the string through the bottom pulley, then back up and around the wheel of the top pulley, then back down through the wheel of the bottom pulley for the second time, and back up through the wheel of the top pulley. Now the string has wound twice through the two pulleys.

Step Four: Pull on the string and compare the force needed to lift the water bottle to the one pulley system described previously.

Pulleys and Force

Student Resource:

What is Force? What are Pulleys?

◆ Force

By pushing or pulling on an object we give it energy and cause it to move, stop moving, or change direction. For example, when we lift a water bottle we exert force on it to cause it to lift in the air. Similarly, the liquid in the bottle exerts a force on the wall of the water bottle. The force may produce motion of the body or may cause the body to deform. Energy may be expended in the process, or the applied force may be balanced by an opposing force so that no energy is expended.

◆ Sir Isaac Newton

Sir Isaac Newton (1642-1727) was the first to state the basic laws of motion of bodies. He presented three fundamental principles:

1. Newton's first law states that every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force. This is normally taken as the definition of inertia.
2. The second law explains how the velocity of an object changes when it is subjected to an external force. The law defines a force to be equal to change in momentum (mass times velocity) per change in time.
3. The third law states that for every action (force) in nature there is an equal and opposite reaction. In other words, if object A exerts a force on object B, then object B also exerts an equal force on object A.

◆ What is a Pulley?

A pulley is a rotating wheel with a curved convex rim which is mounted on a hook or base for stability. A rope, belt, or chain can move along the wheel's rim to change the direction of a pulling force. Examples are a flagpole and a curtain rod. A "single-fixed pulley" is a pulley that is attached to an object. A "single-moveable pulley" is a pulley that is attached to a wire or rope so that it can move with the wire or rope. A "single-fixed pulley" gains nothing in force, distance or speed, but it changes the direction of the force. A system of pulleys may be used to improve leverage in lifting weights, thereby reducing the force required to move an object.

◆ Pulley Application: The Elevator

Pulley systems are used in many machine designs and especially for moving and lifting very heavy equipment and goods. The elevator is an example of a pulley system designed to lift weights. Most elevators use counterweights which equal the weight of the elevator plus about 40% of the maximum weight it will carry. The counter-weight reduces the amount of weight that motor must pull. In a lifting drum installation, a hoist cable runs from a drive drum attached to the motor, runs around a very large pulley attached to the top of the elevator, then runs up to a second pulley attached to the roof of the elevator shaft, and then runs down to the counterweight.



Pulleys and Force

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Student Worksheet:

◆ Engineers use pulleys in all sorts of applications. Here's your challenge -- design a plan that uses two pulleys to lift up a water bottle. Draw your plan in the box below.

◆ Draw a plan for using four pulleys to lift your water bottle.

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Student Worksheet:

◆ Questions:

1. Do you expect the force you will have to apply to move the bottle will be reduced? By how much?
2. Do you think that adding ten more pulleys would make a difference? Why, or why not?
3. Do you think the size of the pulley impacts how much force is needed to lift the bottle? Why, or why not?
4. Do you think the smoothness of the rope or twine pulley impacts how much force is needed to lift the bottle? Why, or why not?
5. Did you find you had to pull the rope or twine further the more pulleys you added to your system?
6. Can you think of examples of three machines that incorporate pulley systems?
7. Can you think of engineering problems that were solved through the use of a pulley or a pulley system?
8. Can you find any examples of pulleys in your school, home, or community?

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For Teachers:

Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (<http://www.nextgenscience.org/>)
- International Technology Education Association's Standards for Technological Literacy (<http://www.iteea.org/TAA/PDFs/xstnd.pdf>)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (<http://www.nctm.org/standards/content.aspx?id=16909>)
- U.S. Common Core State Standards for Mathematics (<http://www.corestandards.org/Math>)
- Computer Science Teachers Association K-12 Computer Science Standards (<http://csta.acm.org/Curriculum/sub/K12Standards.html>)

◆ **National Science Education Standards Grades K-4 (ages 4-9)**

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ◆ Properties of objects and materials
- ◆ Position and motion of objects

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ◆ Abilities of technological design

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ◆ Science as a human endeavor

◆ **National Science Education Standards Grades 5-8 (ages 10-14)**

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ◆ Properties and changes of properties in matter
- ◆ Motions and forces
- ◆ Transfer of energy

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ◆ Abilities of technological design
- ◆ Understandings about science and technology

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- ◆ Science as a human endeavor
- ◆ History of science

◆ **Next Generation Science Standards Grades 3-5 (Ages 8-11)**

Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

- ◆ 3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

Pulleys and Force

For Teachers:
Alignment to Curriculum Frameworks

◆ **Next Generation Science Standards Grades 3-5 (Ages 8-11)**
Engineering Design

Students who demonstrate understanding can:

- ◆ 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- ◆ 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- ◆ 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

◆ **Next Generation Science Standards Grades 6-8 (Ages 11-14)**
Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

- ◆ MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Engineering Design

Students who demonstrate understanding can:

- ◆ MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- ◆ MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

◆ **Standards for Technological Literacy - All Ages**
Technology and Society

- ◆ Standard 5: Students will develop an understanding of the effects of technology on the environment.
- ◆ Standard 7: Students will develop an understanding of the influence of technology on history.

Design

- ◆ Standard 9: Students will develop an understanding of engineering design.
- ◆ Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Abilities for a Technological World

- ◆ Standard 13: Students will develop abilities to assess the impact of products and systems.

Pulleys and Force