A Guide to Simple Machines

Project Fulcrum

Project Fulcrum is supported by the National Science Foundation and the University of Nebraska, in partnership with Lincoln Public Schools

1. Introduction

1.1. How to Use These Materials

1.1.1. Philosophy. Project Fulcrum is based on the strategy shown in Figure 3.9. The first aspect of planning a lesson is deciding what it is you want your students to know and/or be able to do. The second step is to determine what criteria you (or the CRTs) will use to evaluate whether they have learned the items you picked in the first step. The final step is to pick those activities, materials, etc. that will accomplish your goal and facilitate your evaluation of your students. Don't get in the habit of picking the activity first. Activities should serve your goals for your students, not vice-versa.

1.1.2. Background Material. The background material in this section includes information on the basic concepts required to understand Simple Machines, plus some additional materials on nature of science, technology and history.

1.1.3. Objectives. Each LPS objective is stated, and then the fundamental concepts that are necessary to master the objectives are discussed, with references to the appropriate background sections.

1.1.4. Key Concepts. Each objective has multiple smaller ideas, all of which are necessary to understand if students are to meet the objectives. These are presented as bullets, with the goal being to be as specific as possible.

1.1.5. Activities. The activities are not presented in a specific order. You should choose activities via the goals they address. You may plan different activities for different sets of students, depending on their needs and their sophistication. Do not assume that the order in which they are presented here necessarily is the order in which you should utilize them.

1.1.6. Work in Progress. This is a work in progress and is only a draft at this point. We welcome your input, ideas and other contributions.

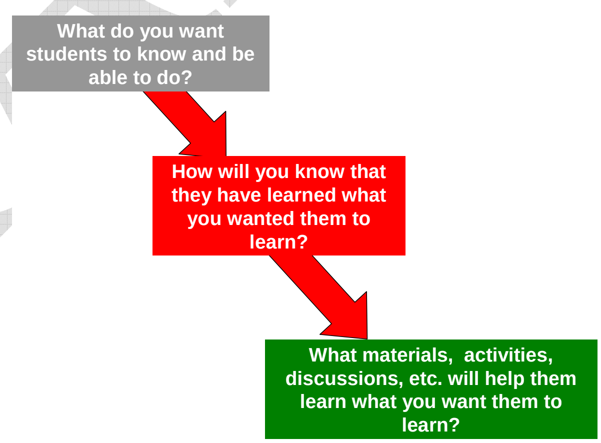


Figure 1.1: Lesson design philosophy

1.2. Opportunities to Work with a Project Fulcrum Scientist

Project Fulcrum scientists are graduate students pursuing advanced degrees in math, science or engineering. They will plan with you to identify hands-on activities and other resources that can help your students master the LPS objectives for the particular unit.

Project Fulcrum scientists are not teachers: they are there to partner with you and help you achieve the goals you have for your students. Working with a Project Fulcrum scientist has many benefits

- An opportunity for your students to make contact with a working scientist and broaden their image of science and scientists;
- Content expertise, including innovative ways to demonstrate and experiment with concepts that sometimes are difficult to teach;

- Increased opportunities to use hands-on, inquiry-based experiences to help your students learn.

One 'Lead Teacher' is required for each school. Preference will be given to schools that have teachers interested in working with the Lead Teacher on the same unit. Lead Teachers from different schools will meet to share ideas and resources, forming a community of practice based around a specific content unit. The Lead Teacher has the following responsibilities:

- Attend a three-hour hands-on content workshop prior to the start of the unit.
- Attend a two-hour Project Fulcrum orientation meeting to learn how Project Fulcrum works
- Attend a two-hour planning meeting prior to starting the unit
- Complete a weekly journal during the time you are working on the unit
- Attend a two-hour meeting at the midpoint of the unit
- Attend a two-hour end-of-unit meeting
- Participate in pre- and post-surveys
- Write a final reflective essay on how the experience has affected the way you teach science
- Communicate with other teachers at the school who are participating.

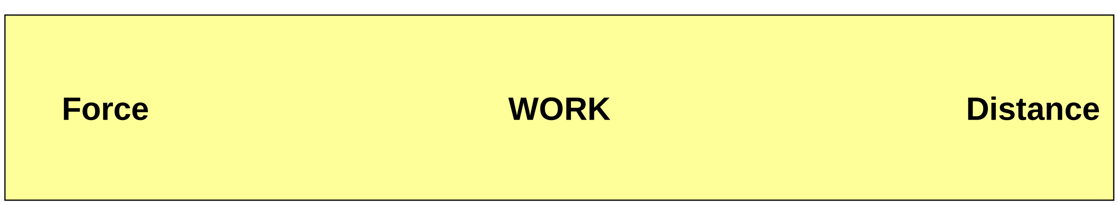
Lead teachers will be paid at the rate of $18/hr (with one hour allotted for each journal). All payments are made at the end of the quarter in which the unit is taught.

2. Background

The Simple Machines Unit has one overarching concept, which is that of work. Work is the amount of energy it takes to raise, drag, lift or otherwise move an object. For example, to lift a book up to a shelf requires you to do work against gravity. Dragging an object across a rough floor requires you to do work against friction.

In general, the work is related to the force you must exert and the distance over which you must exert it as:

$$\text{Work} = \text{Force} \times \text{Distance}$$



Cut out the figure above. If you hold it in the middle, it shows you that, if the force increases (raise the side with 'Force' on it), the distance needed to do the same amount of work decreases (the side with 'Work' on it goes down). If the force decreases, the distance increases.

A machine is a mechanical device that transmits, modifies, or changes the direction of force in order to help people do work. A simple machine is any device that requires only the application of a single force to work. Simple machines include the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw. A compound machine is any machine that uses more than one simple machine. Gears are compound machines because you always use two or more gears together.

3. Objectives

3.1. Summary of Objectives

The student will be able to:

3.4.1 develop an understanding of the concepts of force and friction.

3.4.2 explore and understand the three classes of levers and explain how they make work easier.

3.4.3 explore and understand wheels and axles and discuss the ways they can help dcrease force, increase distance, and decrease friction.

3.4.4 develop an understanding of how inclined planes make work easier.

3.4.5 explore and understand gear systems and explain how they make work easier.

3.2. Objective 3.4.1: Force & Friction: The student will be able to develop an understanding of the concepts of force and friction.

3.2.1. Key Concepts

- Force is the effort you exert to do work. The terms 'force' and 'effort' may be used interchangeably.
- Mass is the amount of matter an object contains.
- Gravity is the force that objects exert on each other. The force of gravity increases as the mass of the objects involved increases, and decreases as the objects get further away.
- Weight is the product of the mass and the acceleration due to gravity. Weight is the force that gravity exerts on an object.
- If two objects are subject to the same force, the one with less mass will go further.
- Friction always acts in the direction opposite the direction an object moves.
- Friction produces heat.

3.2.2. Force. A force is a push or pull. A force may be due to something you can see, like a hand, or something you can't see, like gravity. When you move an object, you do work on the object to overcome the forces that oppose motion.

When raising objects, you are doing work against the weight of the object. Objects have weight due to the pull of gravity on them. Gravity always pulls objects toward the center of the Earth (which is down for objects on the surface of the Earth).

When we are moving objects horizontally over some surface, the force we have to overcome is the force of friction. In most cases, the frictional force is proportional to the weight of the object times some factor that accounts for how rough or slippery the floor is.

The force needed to accelerate an object (get it moving from rest) is proportional to the mass of the object. A lighter object will go further than a heavier object if they both are pushed with the same force.

3.2.3. Loads and Resistance. The object you are moving is the load or resistance. A load or resistance is characterized by its mass. An object with a larger mass offer more resistance to motion.

3.2.4. Gravity. All objects exert a gravitational force on each other. Although people exert gravitational forces on each other, the mass of the Earth is so large that when we talk about gravity in our everyday lives, we are referring to the force that the Earth exerts on everything else. Gravity acts toward the center of the Earth, which we perceive as down.

3.2.5. Building a Better Launcher for Roll On (TG C60-61)

Goal: *Students will learn that if the distance an object travels goes up when the mass of the object goes down (force constant) and goes up if the force goes up (mass constant).*

If the force (which is proportional to the amount the rubber band is stretched back) is held constant, then an object with greater mass will travel a shorter distance than an object with a smaller mass. They also can pull the rubber band back by different amounts to change the force. If the mass of the truck is held constant, the larger the force, the further the truck will go.

A launcher may be made from two C-clamps and a rubber band. The launcher is a modification of the two-pencils-and-a-ruler set up that is recommended in your book (page C60-61). The advantage of the launcher is reproducibility: Students may not always place the pencils is the same spot, or may move during the release. The launcher also minimizes the chance of students get stung by rubber bands if they break. This device will help you have a more constant and reproducible force for any experiments you do regarding force. A photograph is shown in Figure 3.1. Templates for the scale are available on the Project Fulcrum Website:

http://www.physics.unl.edu/~fulcrum/units/simplemachines3/PF_AY05_simplemachines3.php

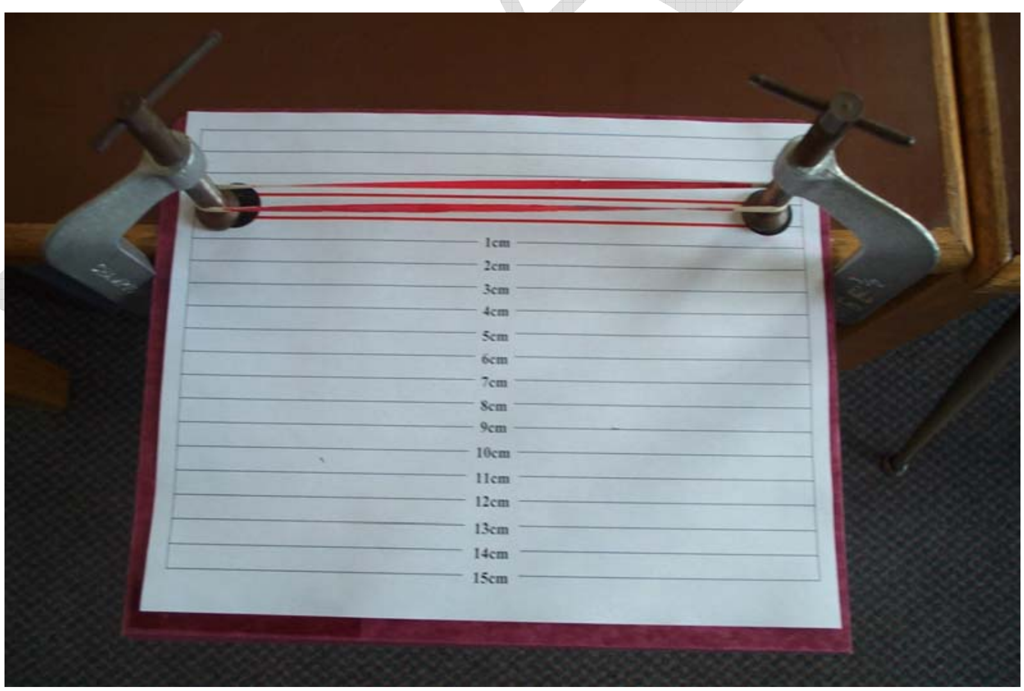


Figure 3.1: A launcher. Templates for making the launcher are on the PF website.

3.2.6. Activity: Investigating Gravity (Gravity Roll C62-63)

Goal: *Students will learn that when an object is released from a higher distance, it will travel further than an object released from a lower distance.*

Comments: Make sure that the board you use is very smooth. If it is rough, you will be investigating friction instead of gravity.

Emphasize making a prediction before doing each trial. Ask the students if they double the height, how much further they think the truck will travel. Have them record their predictions and compare their predictions to their measurements. See if they start making more accurate predictions as they do more trials.

Talk to the students about repeating trials. Scientists rarely depend on one trial: They often make two or three trials (or more) with the same conditions to make sure that they are getting a representative measurement. Have the students repeat the trials at the same height a couple of times and see if they are getting the same results.

Challenge: Ask the students to predict what will happen if they increase the mass of the truck. Will the truck go farther when it is heavier than it does when it is lighter?

3.2.7. Activity: Investigating Friction

Goal: Students will learn from this activity that different surfaces provide different amounts of friction. From the macroscopic bumps on sandpaper, students should be able to understand that even surfaces that appear very smooth to the eye have microscopic bumps that act to retard motion. The use of post-it notes helps students see how friction acts to slow motion.

Materials: A variety of surfaces: waxed paper, coarse and fine sandpaper, etc.; Masking tape; Blocks of wood (approximately the same size); Post-It notes; Launcher (see above); Measuring stick; magnifying glass.

Procedure: Start by taping large pieces, approximately 1 square foot, of the different surfaces (waxed paper, coarse and fine sandpaper, etc.) to the table using masking tape. Have students slowly slide the wood blocks across the different surfaces. Students should observe that it is easier to slide the block across the waxed paper than it is the sandpaper; it is easier to slide the block across the fine sandpaper than the coarse sandpaper, etc. Use the magnifying glass to have students investigate the nature of the different surfaces.

This activity could be modified by attaching strings to the wood blocks and having the students pull the blocks across the different surfaces (as in the Ramps and Rocks activity) –the results should be the same.

To demonstrate one way to reduce friction, line up several straws and have them slide a wood block across the top of the straws. The students should notice that the straws significantly reduce the friction.

To emphasize how surfaces slow down motion via friction: Stand 15 sticky notes (Post-Its) about 4 cm apart in front of a launcher. When the block is launched, the post-it notes will slow the block down. Students will see directly that the frictional force always acts opposite the direction of motion.

Emphasize to the students that, even though many surfaces appear smooth to the eye, they all have bumps and dips on them like the sandpaper. The bumps and dips on a table, for example, are so small that you can't see them, even with a magnifying glass; however, they still contribute to producing friction. The smaller the bumps, the less friction.

3.2.8. Activity: Friction Produces Heat

Goal: Students will understand that friction always produces heat, and that friction always occurs when two materials rub against each other.

Materials: Several small metal cans; several pieces of ribbon approximately 1 foot long; a thermometer.

Procedure: Have students rub their hands together and ask them to record what they observe. The general consensus should be that their hands feel warm after rubbing. They may need to place their hands on their cheeks or some other body part that hasn't been rubbed to notice a difference.

Have pairs of students place a small amount of water in a metal can and measure and record the temperature of the water. One student should place a hand on top of the can to hold it against a table or desk. The other student should take the piece of ribbon and pull the ribbon back and forth across the can. This should be done in the region where the water is for maximum effect. After a few minutes, students should measure the temperature of the water in the can and should find that the temperature of the water is a few degrees higher. The increase in temperature is due to friction between the ribbon and the can. The can is a good thermal conductor and thus can transfer the heat to the water.

3.3. Objective 3.4.2: Levers: The student will be able to explore and understand the three classes of levers and explain how they make work easier.

3.3.1. Key Concepts

- Levers can reduce the amount of force necessary to do a job, such as lifting a box.
- Some levers change the direction of the force – for example, if you push down on a see-saw, the other end of the see-saw goes up.
- A lever is made from a fulcrum, or point of support, and a long, stiff board. The lever pivots about the fulcrum.
- Moving the position of the fulcrum changes the amount of force you must exert. The closer the load is to the fulcrum, the less force is required.
- There are three classes of levers (which are described below). Students should be able to identify what type of lever an object is and explain the advantages and disadvantages of each.

3.3.2. Types of Levers

A lever is a simple machine that consists of a long plank and a fulcrum, or pivot point. A lever uses a force to move a load or resistance. The three classes of lever are illustrated in Figure 3.2.

A first-class lever

- Has the fulcrum in the middle
- The effort and the resistance are applied at opposite ends of the lever
- The effort and the resistance move in opposite directions
- More force must be applied the closer the fulcrum is to the load.
- Examples of first-class levers: See-saws, oars, catapults, pry bar, handcarts

A second-class lever

- Has the resistance in the middle
- The effort and the fulcrum are applied at opposite ends of the lever

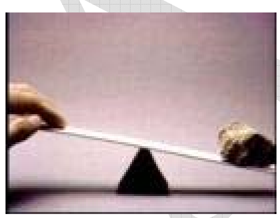
- The effort and the resistance move in the same direction
- Because of the configuration, second-class levers always require less force before the effort is always further from the fulcrum than the load
- Examples of second-class levers: Wheelbarrows, toe-nail cutters, the hood of a car, paper cutters, doors

A third-class lever

- Has the effort in the middle
- The load and the fulcrum are applied at opposite ends of the lever
- The effort and the resistance move in the same direction
- Third-class levers allow the resistance to move a larger distance or at a faster rate than might be possible without the lever.
- Examples: A baseball bat, golf club or tennis racquet being swung, A rake being used to pick up leaves, a split drawbridge, fishing rods

Double levers are two levers that work together. Pruning shears, scissors and similar items are double first-class levers, nutcrackers are double second-class levers, and ice tongs or tweezers are examples of double third-class levers.

A tricky one: A hammer is not a double lever, even though it contains two levers. The hammer head is a third-class lever and the claw is a first-class lever. The two levers are never used at the same time, which is why it is not a double lever.



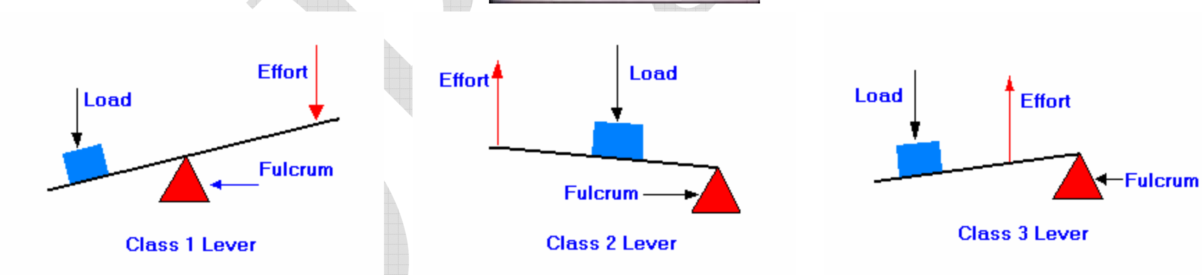


Figure 3.2: Three classes of levers

An easy way to identify the class of lever is to look at the order of the load, effort and fulcrum. A class 1 lever has LFE a second-class lever has ELF and a third-class lever has LEF. This can be either left-to-right or right-to-left.

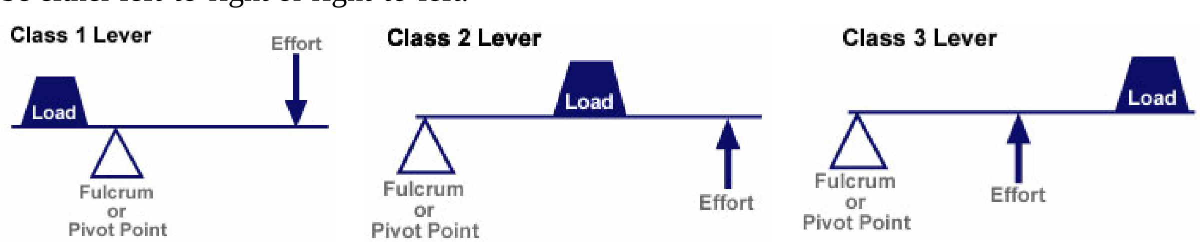


Figure 3.3: Three classes of levers. From left to right: LFE, FLE (flip it to get ELF) and FEL (again, flip it to get LEF)

3.3.3. Activity: Ups and Downs of a Seesaw (C68-69)

Goal: Students will understand that the closer the fulcrum is to the load, the less force is required to life the load.

Comments: At the end of the activity, ask the students to come up with a general rule about how the position of the fulcrum changes the amount of force (effort) needed to lift the clay. They should come up with the above concept: the closer the fulcrum is to the load, the easier it is to lift the load.

3.3.4. Activity: Investigating the Three Classes of Levers

Goal: Students will understand the differences between the three classes of levers, especially in terms of the locations of the effort, load and fulcrum.

Materials: A yard stick or meter stick; any item that may be used as a weight (a small book, balloon filled with sand, etc.); any item that may be used as a fulcrum or pivot point (dowel, toilet paper tube, etc.)

Procedure: Have students create each of the three types of levers as described below and investigate the behavior of the levers.

First Class Lever – Set up the yard stick with the fulcrum in the middle and the weight at one end. Have students push down on the opposite end of the lever. Change the position of the fulcrum (place it closer or farther away from the weight) and have students make observations about how the position of the fulcrum affects the amount of effort required to lift the weight.

Second Class Lever – Set up the yard stick with the fulcrum at one end and the weight in the middle. Have students lift up the opposite end of the yard stick and make observations about how the position of weight affects the amount of effort required to lift the weight.

Third Class Lever – Students will need a partner to create a third class lever. Set up the yard stick with the fulcrum at one end, the partner will need to gently hold the lever against the fulcrum. The student should then place the weight at the opposite end and push upward near the middle of the yard stick. Have the students push upward at various locations along the interior of the yard stick and make observations about which positions require the most effort to lift the weight.

3.3.5. Activity: Identifying the Three Classes of Levers

Goal: Students will be able to identify where the load, the effort and the fulcrum are on different things and from this, determine which class lever the object is.

Materials: A number of objects that are levers. See the lists of examples after the descriptions of the different classes of levers; post-it notes with 'Load', 'Effort' and 'Fulcrum' written on them.

Procedure: Have students place labels 'load', 'effort' and 'fulcrum' on objects around the school and from that, identify the class of each lever.

3.3.6. Activity: Using a Lever to Lift the Teacher

Goal: Students realize that levers allow you to lift an object with less force; however, they often don't appreciate how much of an advantage a lever gives you because the examples they use are *things that they could lift anyway without too much trouble. This activity shows them how much of a help levers can be.*

Materials: A brick or block of wood approximately 2 inches thick; A wood plank about 4-5 feet long; something heavy that the students couldn't life (a teacher, a bucket with heavy books in it, etc.)

Procedure: Using the plank as a lever, place the fulcrum (brick or block of wood) near the middle of the lever. With the teacher (or other object) standing on one end, have the students push down on the other end and try to lift the teacher off the ground. Readjust the fulcrum so that it is closer to the teacher (approximately 1 foot from the end of the plank) and have the students again try to push down on the lever.

Notes: Depending on the ages and abilities of the students, the length of the plank may need to be increased in order to increase mechanical advantage.

3.4. Objective 3.4.3: Wheels & Axles: The student will be able to explore and understand wheels and axles and discuss the ways they can help decrease force, increase distance, and decrease friction.

3.4.1. Key Concepts:

- Wheels and axles provide a way to minimize the effects of friction by decreasing the amount of area that is in contact with the floor.
- Force can be used to turn the axle, which turns the wheel (as in a car), or force can be used to turn the wheel, thus turning the axle (as in a screwdriver)
- Turning the wheel to make the axle go requires less force but greater distance, while turning the axle to make the wheel go around requires less distance, but greater force.

3.4.2. Wheels and Axles. When a wheel is locked to a central axle, turning the wheel forces the axle to move and vice-versa. The wheel turns through a greater distance (the circumference of the wheel), which the axle moves a shorter distance. If you use the wheel to turn the axle, you can use less force. An example of a wheel and axle is a doorknob: the axle is the pin that goes through the door to the other side. A faucet handle and a screwdriver and other examples of wheel-and-axle-type simple machines. (See Figure 3.4)

A crank handle is a hand tool consisting of a rotating shaft with parallel handle. A crank handle often serves as the wheel. Remember that not all wheels look like wheels. (See Figure 3.5)

Figure 3.4: A wheel and axle

Figure 3.5: A crank handle

A winch is a wheel-and-axle that is used to wind up a rope. In its simplest form, it consists of a spool and attached crank handle. More elaborate designs may use gear assemblies or electric drives.

Figure 3.6: A winch

3.4.3. Activity: Wheels are for Rolling

Goal: Students will learn that wheels are round because that is the best shape for rolling. More force is required to move other objects because differently shaped wheels do not allow rolling.

Materials: Plastic straws; plenty of cardboard, construction paper, or poster board; modeling clay

Procedure: Students should cut a variety of shapes from the construction paper (rectangles, squares, ovals, circles, triangles, etc.). Students will need to cut two of each shape. Once the shapes are cut out, have the students use the shapes as the wheels and the straws as the axles. Attach the wheels and axles together with a small amount of modeling clay. Have the students attempt to roll their wheel and axle sets across the table. The students should discover that the round wheel is much easier to roll than any of the other shapes.

Additional Notes: Once the students have observed that the round wheels are the easiest to roll, have the students adjust the axle so that it is not attached at the center of the wheel. Again, the students should discover that placing the axle at the center of the wheel is vital to its efficiency.

This is similar to the activity with the Legos called 'Explore Sliding versus Rolling'. At the end of this activity, they call for you to have the students use larger wheels and repeat the experiment. Be careful because you are changing not just the size of the wheels, but you are also changing the mass of the car. You already have seen that the mass of the car changes how far it rolls. The booklet tells you that larger wheels keep moving for a longer time, but this is a principle of inertia (mass) rather than having anything to do with the simple machine.

3.4.4. Activity: Wheels as Rollers (from LEGO book).

Goal: Reinforce the idea that rolling decreases friction.

3.4.5. Activity: Wheel and Axle as Winch (from LEGO book).

Goal: Illustrate that a longer distance must be covered, although you use less force. If the axle is larger, you cover a longer distance and the force is less than if you use a smaller axle.

Comments: This activity allows you to compare the length of the rope you use to lift something with the distance through which the object actually travels. When the rope winds around the axle, the object doesn't rise as much as the amount of rope. Try using different diameter axles to show this. Unroll the amount of rope that is taken up when the object is lifted and measure it. Compare it to the height the object is lifted. See if the amount of rope used is larger or smaller when the axle is larger.

3.5. Objective 3.4.4: Inclined Planes: The student will be able to develop an understanding of how inclined planes and wedges make work easier.

3.5.1. Key Concepts:

- Inclined planes reduce the amount of force needed to lift an object by increasing the distance the object travels.
- An inclined plane stays stationary, in contrast to other types of simple machines.
- A screw is a rod with an inclined plane traveling around it.
- A screw usually has the shape of a rod or cone
- The distance around the threads of the screw is longer than the length of the screw – that's the extra distance that decreases the force. It is easier to travel around the screw than straight up and down.
- A wedge is a special kind of inclined plane made of two slopes back-to-back.
- A wedge changes the direction of the applied force. You push down on the wedge, but the object the wedge is touching moves sideways.
- Wedges are the only inclined planes that move when being used.
- The longer the inclined plane, screw or wedge, the less force must be exerted.

3.5.2. Inclined Planes. An inclined plane (or ramp) is a flat surface with one end higher than the other. If you light an object through a distance *h*, the amount of work you have to do is the product of the weight and the distance you lift the object. An inclined plane has the same height, but a much longer run. Figure 3.7 shows that the net result is the same, but the distance is longer. The large the ratio of slope length to height, the less force has to be exerted.

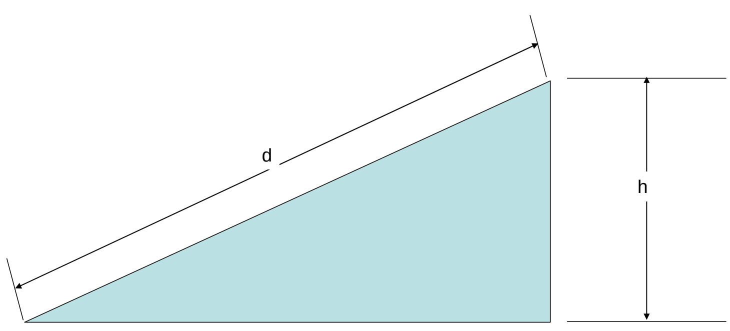


Figure 3.7: An inclined plane. The object going up the plane increases its height by the same distance *h*, but it travels a longer horizontal distance to decrease the force necessary.

Examples include slides, ramps you might use to load a motorcycle on a truck, or boxes onto a moving truck.

3.5.3. Screws. A screw is a rod with an inclined plane circling around it. A spiral staircase is an example of a screw, as are drill bits and – surprise – screws. Imagine climbing to the top of the Statue of Liberty using a ladder. The spiral staircase that was installed takes longer, but it is significantly easier (i.e. less force) to climb.

3.5.4. Wedges. A wedge is an inclined plane with either one or two sloping sides. A wedge converts motion in one direction into a splitting motion that acts at right angles to the wedge. Nearly all cutting machines use a wedge. A lifting machine may use a wedge to get under a load. Examples include doorstops. When you use a wedge to cut, the distance the wedge travels is long compared to the separation of the object you were cutting. as shown in Figure 3.9.

Is a door jam a wedge or an inclined plane? It doesn't move; however, you have to make the decision based on the activity. The door jam exerts a force up and down holding the door in place. Nothing moves along it, so the door jam is a wedge and not an inclined plane.

Most cutting tools are wedges in combination with levers (knives, scissors, shears, axes, etc.).

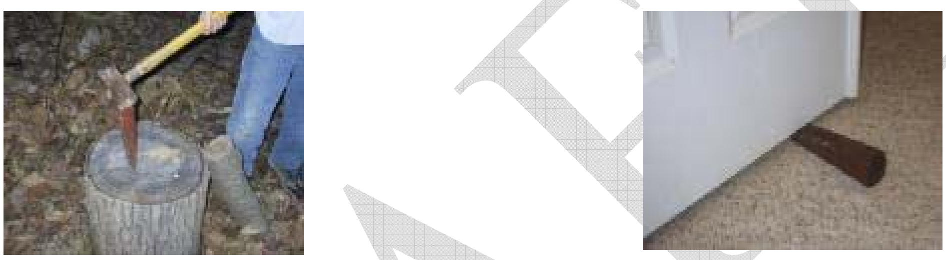


Figure 3.8: Wedges at work. Note that the door stop is an inclined plane, but it is acting as a wedge because the force it exerts is actually up.

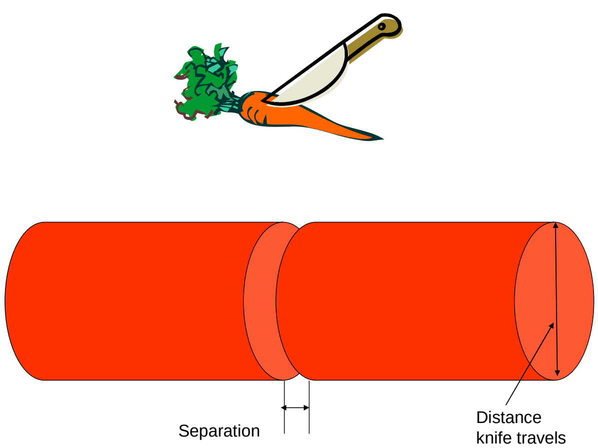


Figure 3.9: An inclined plane

3.5.5. Activity: Making a Screw from an Inclined Plane

Goal: Students will understand that screws are inclined planes wrapped around a rod or cone.

Materials: A square piece of paper; a pencil or straw; rulers, pencils, scissors.

Procedure: Each pair of students should be given one square piece of paper. Have one of the students make a dark diagonal line on a square piece of paper. Have the other student cut along the dark line. Each partner may now use one of the triangles to roll around a straw or pencil starting at one of the sides and rolling toward the pointed end. The students should identify the resulting device as a screw. Have students repeat the experiment with rectangular pieces of paper and have them note the differences between the two screws they made.

3.5.6. Activity: Wedges Allow You to Split Objects

Goals: Demonstrate that a wedge changes the direction of motion: You push down on a wedge, but the motion of the object that the wedge acts on is at right angles to the push.

Materials: A standard (flat) screwdriver (not a Philips screwdriver); pencil with eraser; pieces of corrugated cardboard.

Procedure: Ask the students to try to push the erase into the cardboard. Have the students write their observations about what happens to the cardboard as they push the eraser into it. Then students should then take the screwdriver and gently push the tip of the screwdriver into the cardboard, again making observations about what happens to the cardboard. The students should find that the wedge at the tip of the screwdriver penetrates the cardboard easier than the blunt eraser of the pencil. They also should look at what direction the cardboard moves when the screwdriver is moving straight up and down.

Additional Notes: Disposable plastic knives can substitute for the metal screwdriver. A plastic screw driver also will work.

3.5.7. Activity : Testing Inclined Planes and the Force-Distance Connection. (Ramps and Rocks)

Goal: Students will find that the longer the inclined plane, the less force is needed to pull an object up the plane.

Materials: Light weights, inclined planes of various lengths, but all with the same height; spring scales.

Procedure: Attach the spring scale to the weight and have the student lift it from the table to the same height as each of the inclined planes. Note how much force they have to exert to do this. Then have them use the minimum force it takes to pull the same weight up each inclined plane. The will find that less force is necessary as the distance increases.

3.6. Objective 3.4.5: Gears. The student will be able to explore and understand gear systems and explain how they make work easier.

3.6.1. Key Concepts:

- Gears are *technically* not simple machines because they are made up of two simple machines.
- Gears decrease the amount of force necessary by increasing the distance moved (the distance is around the gear).
- A small gear requires less force to turn than a big gear, but must be turned many times to make a big gear turn once
- Gears can be used to change direction of rotation. When two gears are linked together, they turn in opposite directions and can make different parts of machines turn in opposite directions.
- Gears can be used to change the rate at which something rotates (Gearing up or gearing down)
- Two meshed gears always turn in opposite directions

3.6.2. Gears. The most common type of gear is a wheel with "teeth." This type of gear also is called a spur gear, as shown in Figure 3.10. When a force is applied to the gear, its teeth mesh with those of another gear, transferring the force to the second gear. The turning rate can be changed by using one gear that is larger than another. Anyone who has ridden a bicycle with multiple gears has changed force by adjusting gear ratios.

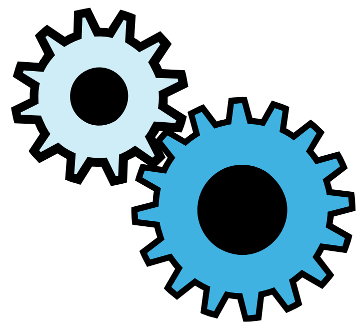


Figure 3.10: Spur gears illustrating gear ratios

A gear ratio is the ratio of either the diameters or the gears or the number of teeth on the gears. In Figure 3.10, the larger gear has 16 teeth and the smaller gear has 12 teeth, so the gear ratio is 16:12, or 1.33:1

A compound gear is a gear that has two or more gears attached to the same shaft, as shown in Figure 3.12. The driver gear is the gear to which the force is being applied, while the follower gear is the gear that is being turned by the driver.

Figure 3.12: A compound gear

3.6.3. Changing the Speed of Rotation

Gearing up is using a combination of gears in which the rotational speed of the output gear is greater than the rotational speed of the input gear. (See Figure 3.11a) When gearing up, the driver gear is always larger than the follower gear. The rotational speed of the output gear to the input gear depends on the gear ratio.

Gearing down is using a combination of gears in which the rotational speed of the follower gear is less than the rotational speed of the driver gear. (See Figure 3.11a) When gearing up, the driver gear is always smaller than the follower gear. The speed of the output gear to the input gear goes like the ratio of the driver diameter to the follower diameter.

An idler gear is a gear that is inserted between two other gears. Idler gears do not affect the gear ratio between the input and output gears; however, they do affect the direction of rotation. By

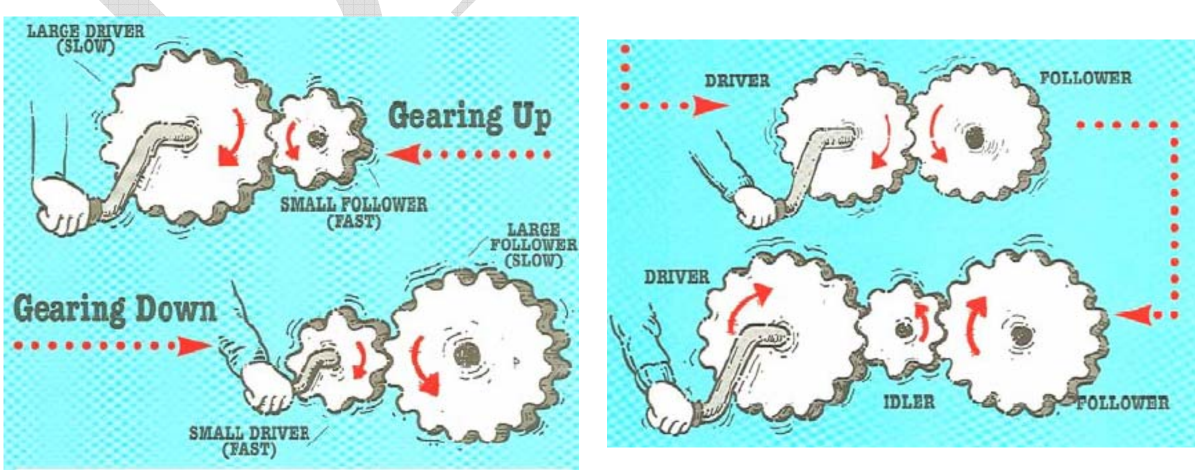


Figure 3.11: a) Gearing Up and gearing down. b) Idle Gearing.

adding an idler gear between the two, the output axle rotates in the same direction as the input axle. (See Figure 3.11b)

3.6.4. Changing the Direction of Motion. Crown or bevel gears are gears that meet at right angles (like on an egg beater), as shown in Figure 3.13. Gears in this configuration allow you to change the direction of motion, which can come in handy if you are in tight spaces.

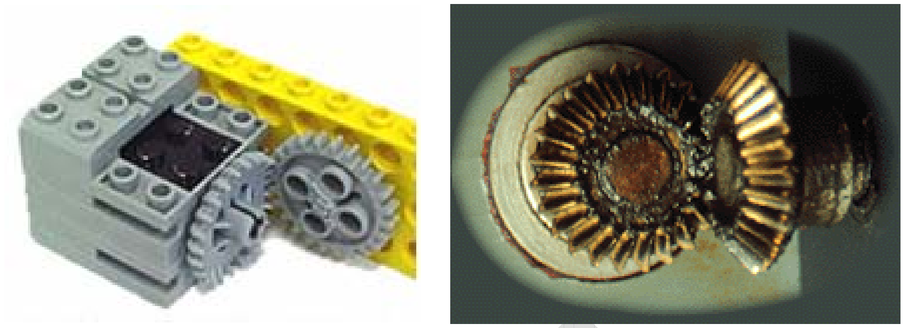


Figure 3.13: a) Bevel or Crown gears from a Lego Set b) From a machine

3.7. Assessments

The following are suggestions for ways that you can check to see whether your students understand the concepts you would like them to learn in this unit.

3.7.1. Can Students Identify Simple Machines in Real-Life Equipment?

Goal: Determine whether students have a good enough understanding of the different simple machine that they can identify simple machines in toys.

Materials: A variety of screwdrivers, hammers, and pliers; A few old and/or broken toys

Procedure: Students break into partners or small groups and begin to “dissect” their toy. As they are dissecting the toy, they should try to identify the removed parts and classify them in a category of simple machines: screws, wheels, etc. Each student should have a basic worksheet on which to make tally marks for each type of machine found:

Screw	Inclined Plane	Pully	Gear	Wheel
𝍸	𝍷	𝍷𝍷	𝍸𝍷𝍷	𝍷𝍷𝍷𝍷

Additional Notes: Students can volunteer to bring in broken toys. Alternately, thrift stores are a good place to find inexpensive toys. Some thrift stores may also be willing to donate broken items that cannot be sold.

3.7.2. Rube Goldberg’s Inventions

Goal: *Determine whether students have a good enough understanding of the different simple machine that they can identify simple machines in toys.*

Materials: Examples of Rube Goldberg machines (see example below). You can download examples from http://www.rubegoldberg.com/html/gallery.htm.

Procedure: Students are given a cartoon of a Rube Goldberg machine, an example of which is shown in Figure 3.14. From the drawings, students should attempt to identify and categorize as many simple machines as possible.

Additional Notes: Rube Goldberg was a cartoonist during the early twentieth century. Goldberg's most popular cartoons featured elaborate machines designed to assist with very simple tasks (as shown by the pencil sharpener detailed above). Goldberg's cartoons are copyrighted and as a result only a few drawings are available for viewing at http://www.rubegoldberg.com/html/gallery.htm; however, books containing hundreds of Goldberg's Inventions are available for check-out at the local libraries. A great science club project would be to have the students make their own Rube Goldberg machines and incorporate as many simple machines as possible.

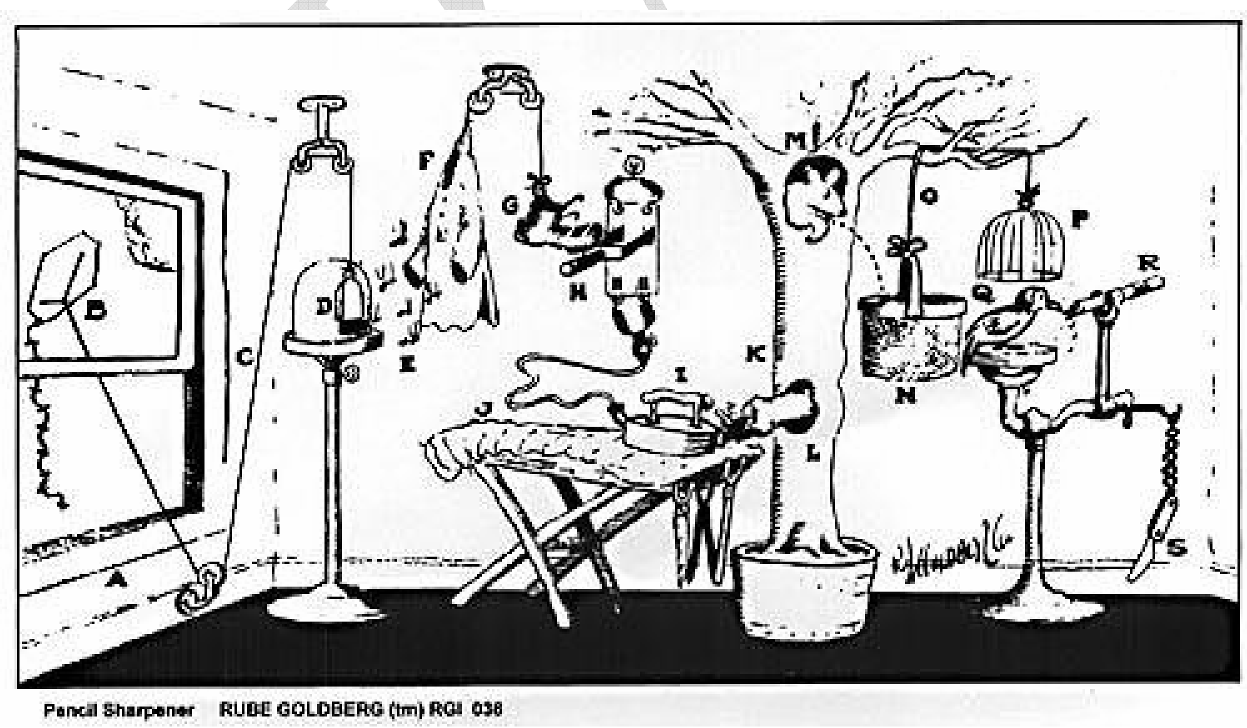


Figure 3.14: A Rube Goldberg Device.

4. Vocabulary

Note: These are not the official LPS definitions -- but they are correct!

Axle - When a wheel is locked to a central axle, as one is turned the other must turn. A longer motion at the edge of the wheel converts to a shorter more powerful motion at the axle. In reverse, a short, powerful force at the axle will move the wheel's edge a greater distance.

Bevel Gear: A gear in which the teeth are at a 45-degree angle so that two gears can meet at right angles to each other. Also called a **crown gear**

Compound Gear - A compound gear is a gear that has two or more gears attached to the same shaft.

Compound machine: A machine that is made up of more than one simple machine.

Crank Handle – A crank handle is a hand tool consisting of a rotating shaft with parallel handle.

Crown Gear: A gear in which the teeth are at a 45-degree angle so that two gears can meet at right angles to each other. Also called a bevel gear

Driver gear: the gear in a compound gear to which the force is being applied

An **effort** is the exertion of a force.

A **force** is a push or pull. A force may be due to something you can see, like a hand, or something you can't see, like gravity.

Follower gear: The gear in a compound gear that is being turned by another gear.

Friction is a force that always acts in the direction opposite motion. Occurs when two objects slide against each other. Friction is greater on rough surfaces than it is on smooth surfaces.

Fulcrum - The point of support of a lever, around which it moves.

Gear - The most common type of gear is a wheel with "teeth." When force is applied to the gear, its teeth mesh with those of another gear, transferring the force to that gear. When one gear is larger than another, the rotation rate changes. Adjusting relative gear sizes, or gear ratios, gives us a way to the direction of rotation or the speed of rotation.

Gear ratio is the ratio of either the diameters or the gears or the number of teeth on the gears. If the gear ratio is greater than one, the gear system is gearing up and if it is less than one, the gear system is gearing down.

Gearing down is using a combination of gears such that the follower gear rotates more slowly than the driver gear.

Gearing up is using a combination of gears such that the follower gear moves faster than the driver gear.

An **idler gear** is a gear inbetween two other gears that allows the two other gears to both rotate in the same direction.

An **inclined plane** (or ramp) is a flat surface with one end higher than the other.

Gravity is a force that all objects exert on each other. The source of gravity on the Earth is the large mass of the Earth itself, which causes object to fall downward when dropped.

Lever - A lever is a stiff rod or plank that rotates around a fixed point, or fulcrum. Downward motion at one end results in upward motion at the other end. Depending on where the fulcrum is located, a lever can multiply either the force applied, or the distance over which the force is applied. There are three kinds of levers, and which kind you have depends on where the fulcrum is set.

Load: A load is the object you are doing work on. This may also be called the resistance.

Machine - A mechanical device that transmits, modifies, or changes the direction of force in order to help people do work. A simple machine is any device that only requires the application of a single force to work, such as the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw.

Mass: the amount of matter in an object. The weight of an object is its mass times the acceleration due to gravity.

Ramp – A ramp is an inclined plane or surface that connects two levels of unequal height.

Resistance: See Load.

Screw: A screw is a rod with an inclined plane circling around it.

Simple Machine – A simple machine is any of the various elementary devices considered as the elements from which all other machines are composed, including the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw. A simple machine only requires the application of a single force to work.

Spur Gear: A gear that has teeth around its outside. (See Figure 3.10)

A **wedge** is an inclined plane with either one or two sloping sides. The important distinction about a wedge is that the force is exerted downward, but the force the wedge exerts on the object is sideways.

Winch: a wheel-and-axle that is used to wind a rope around the axle. The length of rope required is much greater than the distance that the object is lifted; however, less force is required.

Work is the product of force times distance. If you move an object horizontally or vertically, the same amount of work must be done no matter what method you use. Machines allow you to move the object over a larger distance with less force, or over a shorter distance with more force.