2.1 Physical Systems: Simple Machines

Figure 1 Which simple machine is part of a stapler?

Imagine trying to put a staple through a stack of paper with your bare hands! It is an almost impossible and dangerous task. A stapler gets the job done quickly, easily, and safely (Figure 1). What is it about a stapler that makes stapling easy? A stapler is a system that is specifically designed to accomplish stapling.

Most staplers are long, rigid devices made of plastic or metal. The top arm holds the staples, and the bottom arm forms a base that sits on a desk. One end of the top is attached to the base with a hinge that allows the arm to move smoothly up and down. This arrangement of arms forms a simple machine. A **simple machine** is a device, composed of only one or two parts, that requires a single force to work. The stapler works by applying a single downward force at its open end. Like the stapler, the mechanisms of most physical systems are made of one or more simple machines that work alone or together to make physical tasks such as nailing, cutting, throwing, carrying, chopping, and prying easier to do.

simple machine: a device that requires a single force to work; made of only one or two parts

There are six simple machines: the inclined plane, the wedge, the screw, the lever, the wheel and axle, and the pulley (Figure 2). These simple machines can be categorized into two groups—those related to the inclined plane (the wedge and the screw) and those related to the lever (the wheel and axle and the pulley).

To learn more about simple machines,
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(a) The inclined plane

(b) The wedge

(c) The screw

(d) The lever

(e) The wheel and axle

(f) The pulley

Figure 2

The Inclined Plane, Wedge, and Screw

If you lift one end of a book and leave the other end on your desk, you have created a simple inclined plane. The word *plane* means "flat surface" and *inclined* means "tilted." Therefore, an inclined plane is a tilted, flat surface.

Ramps are the most easily recognized inclined planes. A less obvious inclined plane is a staircase—stairs are a ramp with flat spaces built in. Knives have cutting edges shaped like a wedge. A wedge is a modified inclined plane that can be moved back and forth with ease. An axe is a wedge attached to a handle so that it can be moved quickly and with great force. A spiral staircase (Figure 3(a)) is an inclined plane that has been wrapped around a central core (Figure 3(b)). A screw is actually an inclined plane that has been cut into a central core.

The Archimedes' screw (Figure 4(a)) is a device used in many cultures to lift water. Modern versions of the Archimedes' screw are also used to move sludge in sewage treatment plants and to gently move fish within fish hatcheries. Two augers, or modified Archimedes' screws, are used in a Zamboni to clear the ice on hockey rinks (Figure 4(b)).

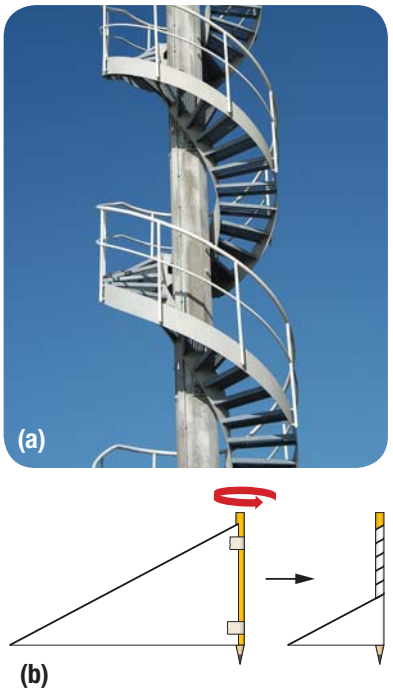
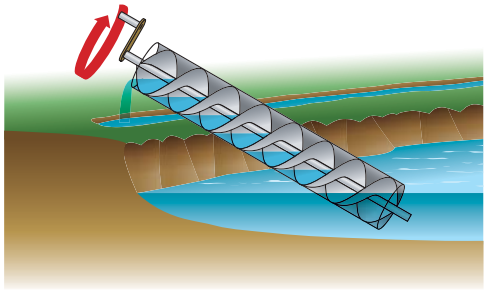


Figure 3 A spiral staircase is an inclined plane wrapped around a central core (a), as can be shown with a paper triangle and a pencil (b).



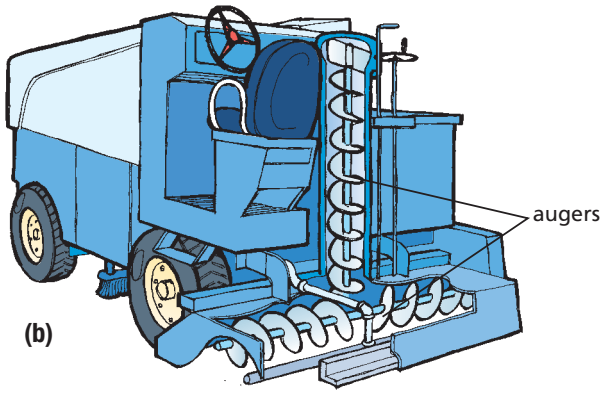


Figure 4 (a) An Archimedes' screw is used for lifting water. (b) In a Zamboni, two augers work together to collect ice shavings from the ice surface and move them into a collection tank.

LINKING TO LITERACY

Reading a Diagram

Diagrams are visuals that help you understand what is written in the text. Figures 4(a) and (b) are described in the paragraph above. As you read the text, move back and forth between the text and diagram to help you understand each idea.

Levers

A lever is a rigid bar that pivots at a point called the **fulcrum**. The **load arm** is the part of the bar between the fulcrum and the object (load) you want to move. The **effort arm** is the part of the bar between the fulcrum and where the effort is applied (Figure 5 on the next page).

fulcrum: the pivot point of a lever

load arm: the part of a lever that extends from the fulcrum to the mass being moved

effort arm: the part of a lever that extends from the fulcrum to where the force is applied

input force: the effort force applied to the lever

output force: the force the lever applies to the load

load force: the force that the input force has to overcome in order to cause movement

Levers form the basis of many tools, including scissors, some door handles, backhoes, and ladder trucks. Levers are designed so that the force applied to one part of the lever can be changed or redirected in order to move a load. The **input force** is the force applied by the user. The **output force** is the redirected push that the lever applies to the load. The **load force** is the force that the user's input force has to overcome. The load force is sometimes called resistance. In Figure 5, the acrobat on the right applied the input force when he jumped on the launcher. The output force is the force that pushed the acrobat on the left into the air. The load force that the input force had to overcome was the weight of the acrobat on the left, when he was standing on the launcher.

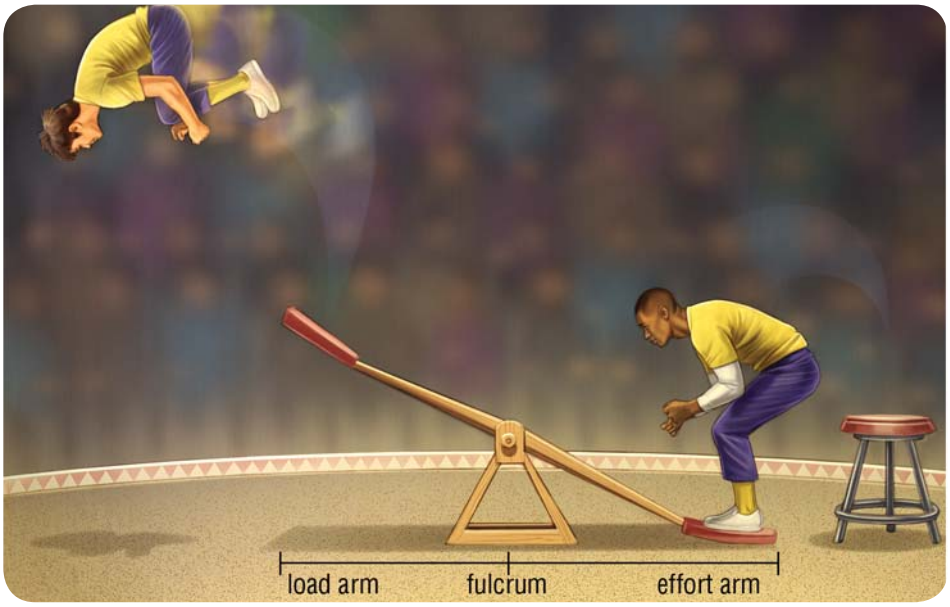


Figure 5 The desired output of this lever is the upward force needed to toss the performer into the air.

LINKING TO LITERACY

Visualizing

When we read, we create pictures in our mind to help us understand what we are reading. As you read this section, think about the pictures created in your mind when you read words such as lever, wheel and axle, gear, and pulley.

Levers are divided into three classes:

Class 1 levers (Figure 5): the fulcrum is between the load force and the input force

Class 2 levers (Figure 6): the load force is between the fulcrum and the input force

Class 3 levers (Figure 7): the input force is between the fulcrum and the load force

Figure 6 A wheelbarrow is a class 2 lever.

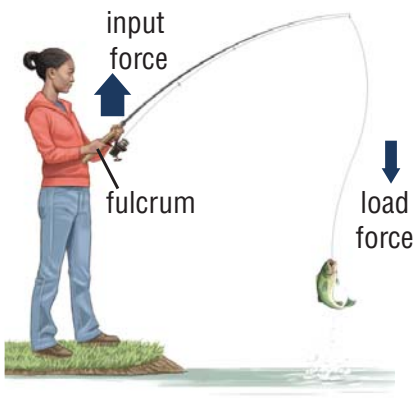


Figure 7 A fishing rod is a class 3 lever.

Wheel and Axles, Gears, and Pulleys

Rotary motion, or turning motion, is a part of many physical systems, either as an input, as an output, or both. Often, the turning motion is transferred to another part of the system through the use of wheels, pulleys, and gears. For example, when you ride a bicycle, the gears and chain transform the rotary motion of the pedals into the rotary motion of the back wheel.

Figure 8 shows a well with a bucket that is raised and lowered by turning a crank. The crank is a modified lever that rotates around its fulcrum.

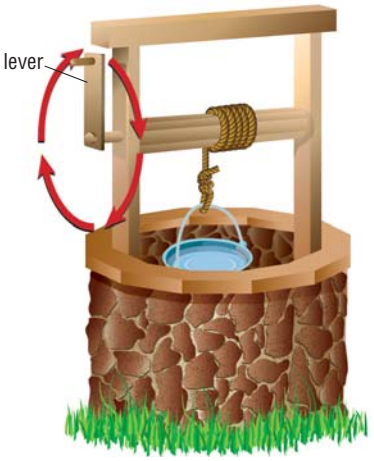


Figure 8 This simple machine turns rotary motion into the up, and down, linear movement of the bucket.

Wheel and Axles

The wheel and axle is the most common wheel mechanism. It consists of a large diameter disk (wheel) attached to a small diameter shaft (axle). Using the wheel to turn the axle changes a small input force into a larger output force. For example, a car's steering wheel (Figure 9) has a greater diameter than the steering column (axle). A small force on the steering wheel creates a larger force on the axle and, therefore, a larger force on the wheels of the car. However, the greater diameter of the steering wheel means the driver's hands travel farther than they would if he had applied the force to the column itself. The distance travelled may be more, but it is much easier to turn the larger wheel than it is to turn the axle.

To learn more about wheel and axles,
Go to Nelson Science

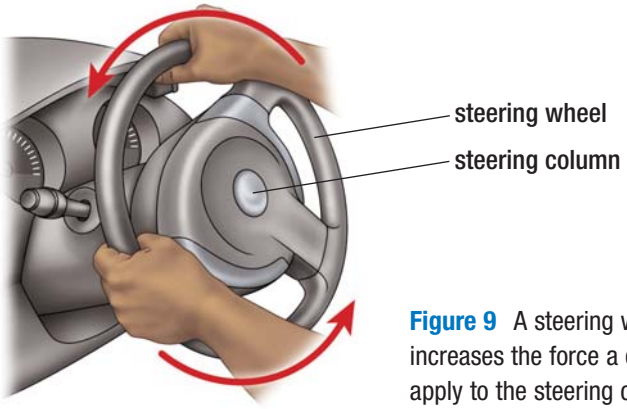


Figure 9 A steering wheel increases the force a driver can apply to the steering column.

Wheel and axles sometimes work in the opposite way: a large input force on the axle is used to gain an advantage in distance. This property is demonstrated by a child's top (Figure 10). To spin a top, a large input force is applied to the handle (axle). This causes the top to spin very quickly because the body of the top travels a much greater distance than the handle does in the same amount of time.

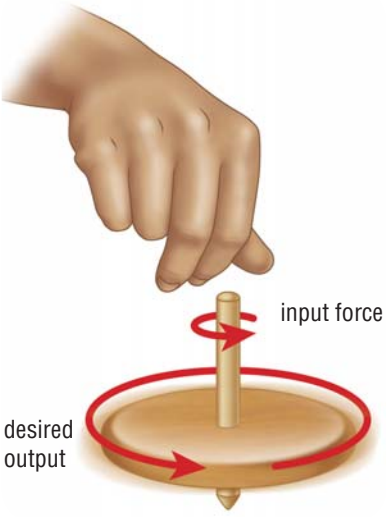


Figure 10 Turning the axle of a top requires a larger input force than if the force was applied to the body.

Depending on the design of the machine or mechanism, wheel and axle devices can be used to transfer rotary motion to rotary motion (for example, turning a bicycle's pedals causes the wheels to turn), rotary motion to linear motion (for example, turning a doorknob moves the latch in or out), or linear motion to rotary motion (for example, pushing a rolling pin causes it to turn).

LINKING TO LITERACY

Labelled Diagrams

A labelled diagram is a useful way to support scientific or technical writing. It can help explain the details of a subject in a clear way. It can also help explain the relationship between different things. As you examine Figures 11 and 12 ask yourself, "How does the movement of one part of the gear affect the other?"

Gears

A gear is a modified wheel and axle. Gears are toothed wheels, most commonly made of metal or plastic. They are used to speed up or slow down motion, or to change the direction of motion (Figure 11). When gears are used in combination with one another, they form a gear train.

Depending on the purpose of the device, gears work either by reducing the input force required to push or pull objects (Figure 12(a)) or by increasing it (Figure 12(b)). Each of these arrangements has specific advantages and disadvantages.

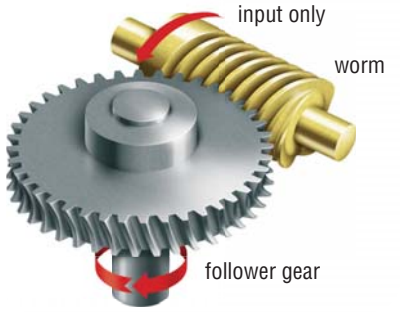


Figure 11 The worm in a worm gear drives a follower gear and can also change the axis of rotation through 90° (for example, the drive mechanism in a toy car).

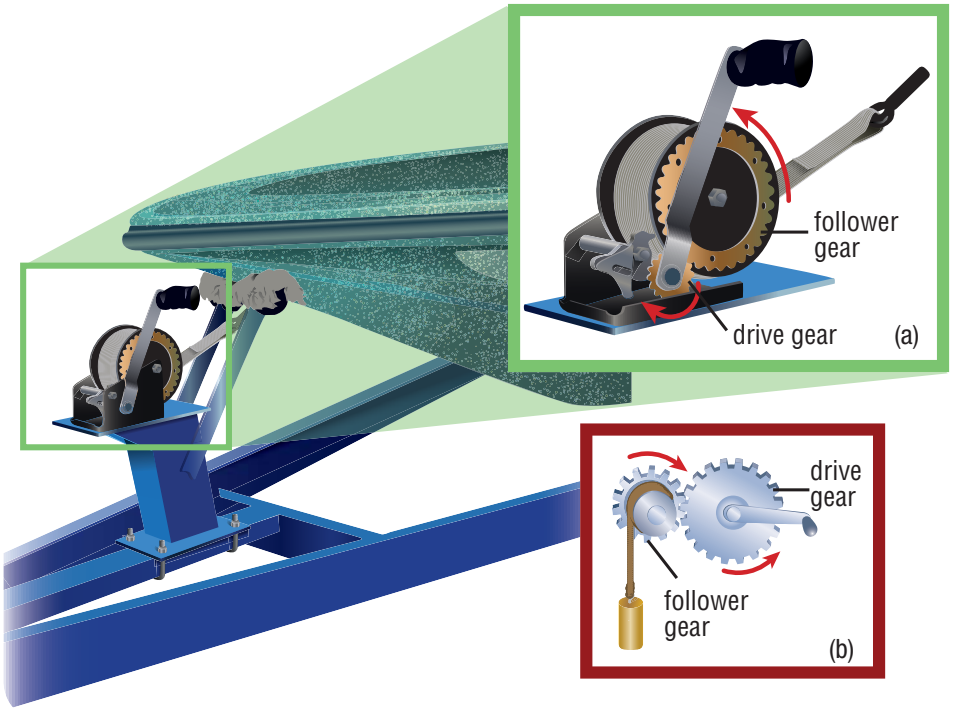


Figure 12 The order of gears in a gear train determines the amount of input force required and the speed of the follower gear.

(a) A small input force on this drive gear can raise a large load. However, the drive gear is smaller with fewer teeth, so it must turn several times for each turn of the follower gear. This type of gear is often seen on a boat trailer as shown in this figure.

(b) A large input force is required in this system. However, the load will be raised quickly, since the follower gear will turn several times for each turn of the drive gear.

Pulleys

Several devices use wheel and axles to make pulling objects easier. A pulley is such a device. Pulleys are used to help lift heavy loads or change the direction of a force. Pulleys can be used by themselves as single pulleys or in combination with other pulleys to create a pulley system. Pulley systems can contain fixed and moveable pulleys. A fixed pulley is attached to a rigid, non-moveable structure at some point; a moveable pulley is not attached to a fixed structure (Figure 13).

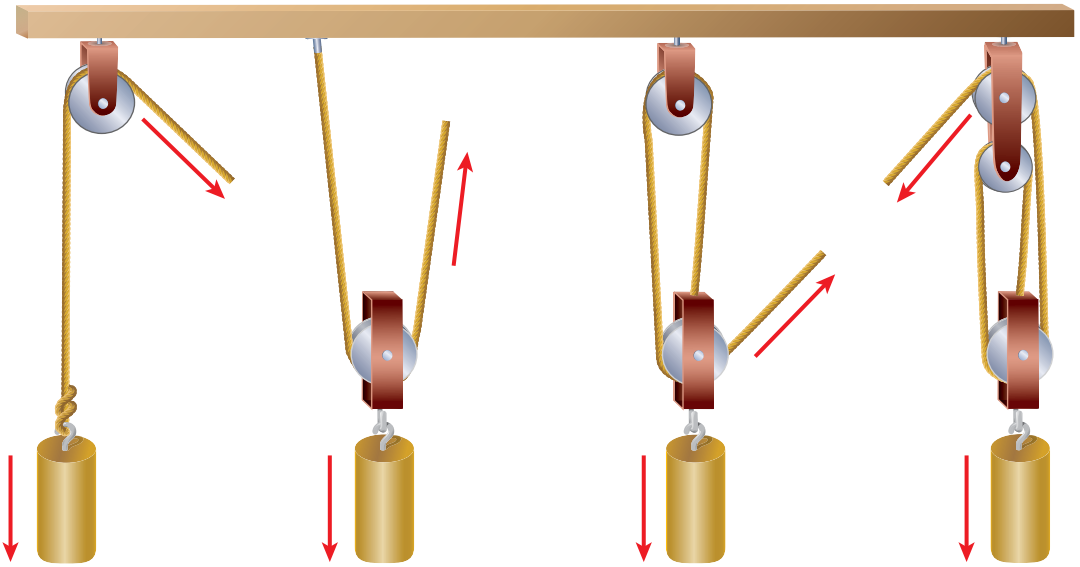


Figure 13 (a) Single, fixed pulley (b) Single, moveable pulley (c) Double pulley system (d) Multiple pulley system

Unit Task How might you use one or more of these machines to help you complete the Unit Task?

CHECK YOUR LEARNING

1. **(a)** Reread to the cartoon in the Chapter 2 Opener. Identify and describe as many simple machines as you can.
   (b) How were the simple machines a help? How did they make the work harder?
2. Which of the six simple machines relates the most to your everyday life? Explain.
3. Describe the relationship between input force, output force, and load force.
4. In your notebook, complete Table 1 below for each of the six simple machines.
5. Which of the following simple machines do you feel has had the greatest impact on humans: the inclined plane, the lever, or the wheel and axle? Explain your answer.

Table 1

Simple machine	Example	How society uses it to make life easier