KEY CONCEPT

5.1 Machines help people do work.

BEFORE, you learned

- Work is done when a force is exerted over a distance
- Some work can be converted to heat or sound energy

NOW, you will learn

- How machines help you do work
- How to calculate a machine's efficiency

VOCABULARY

machine p. 145
mechanical advantage p. 147
efficiency p. 150

EXPLORE Machines

How do machines help you work?

PROCEDURE

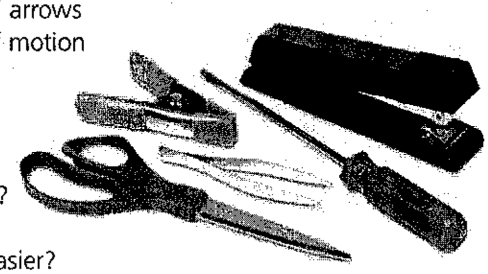
1. Look at one of the machines closely. Carefully operate the machine and notice how each part moves.
2. Sketch a diagram of the machine. Try to show all of the working parts. Add arrows and labels to show the direction of motion for each part.

WHAT DO YOU THINK?

- What is the function of the machine?
- How many moving parts does it have?
- How do the parts work together?
- How does this machine make work easier?

MATERIALS

various small machines

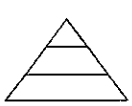


Machines change the way force is applied.

For thousands of years, humans have been improving their lives with technology. Technology is the use of knowledge to create products or tools that make life easier. The simplest machine is an example of technology.

A **machine** is any device that helps people do work. A machine does not decrease the amount of work that is done. Instead, a machine changes the way in which work is done. Recall that work is the use of force to move an object. If, for example, you have to lift a heavy box, you can use a ramp to make the work easier. Moving the box up a ramp—which is a machine—helps you do the work by reducing the force you need to lift the box.

VOCABULARY
Make a word triangle diagram in your notebook for *machine*.



If machines do not reduce the amount of work required, how do they help people do work? Machines make work easier by changing

- the size of the force needed to do the work and the distance over which the force is applied
- the direction in which the force is exerted

Machines can be powered by different types of energy. Electronic machines, such as computers, use electrical energy. Mechanical machines, such as a rake, use mechanical energy. Often this mechanical energy is supplied by the person who is using the machine.

Changing Size and Distance

Some machines help you do work by changing the size of the force needed. Have you ever tried to open a door by turning the doorknob's shaft instead of the handle? This is not easy to do. It takes less force to turn the handle of the doorknob than it does to turn the shaft. Turning the handle makes opening the door easier, even though you must turn it through a greater distance.

A rake is a machine that changes a large force over a short distance to a smaller force over a larger distance.

If a machine—such as a doorknob attached to a shaft—allows you to exert less force, you must apply that force over a greater distance. The total amount of work remains the same whether it is done with a machine or not. You can think of this in terms of the formula for calculating work—work is force times distance. Because a machine does not decrease the amount of work to be done, less force must mean greater distance.

A doorknob allows you to apply a smaller force over a greater distance. Some machines allow you to apply a greater input force over a shorter distance. Look at the boy using a rake, which is a machine. The boy moves his hands a short distance to move the end of the rake a large distance, allowing him to rake up more leaves.

Input force is the force exerted on a machine. Output force is the force that a machine exerts on an object. The boy in the photograph is exerting an input force on the rake. As a result, the rake exerts an output force on the leaves. The work the boy puts into the rake is the same as the work he gets out of the rake. However, the force he applies is greater than the force the rake can apply to the leaves. The output force is less than the input force, but it acts over a longer distance.

CHECK YOUR READING How can a rake help you do work? Use the word *force* in your answer.

Changing Direction

Machines also can help you work by changing the direction of a force. Think of raising a flag on a flagpole. You pull down on the rope, and the flag moves up. The rope system is a machine that changes the direction in which you exert your force. The rope system does not change the size of the force, however. The force pulling the flag upward is equal to your downward pull.

A shovel is a machine that can help you dig a hole. Once you have the shovel in the ground, you push down on the handle to lift the dirt up. You can use some of the weight of your body as part of your input force. That would not be possible if you were lifting the dirt by using only your hands. A shovel also changes the size of the force you apply, so you need less force to lift the dirt.

Mechanical Advantage of a Machine

When machines help you work, there is an advantage—or benefit—to using them. The number of times a machine multiplies the input force is called the machine's **mechanical advantage** (MA). To find a machine's mechanical advantage, divide the output force by the input force.

APPLY How does the rope system help the man raise the flag?

$$\text{Mechanical Advantage} = \frac{\text{Output Force}}{\text{Input Force}}$$

For machines that allow you to apply less force over a greater distance—such as a doorknob—the output force is greater than the input force. Therefore, the mechanical advantage of this type of machine is greater than 1. For example, if the input force is 10 newtons and the output force is 40 newtons, the mechanical advantage is 40 N divided by 10 N, or 4.

For machines that allow you to apply greater force over a shorter distance—such as a rake—the output force is less than the input force. In this case, the mechanical advantage is less than 1. If the input force is 10 newtons and the output force is 5 newtons, the mechanical advantage is 0.5. However, such a machine allows you to move an object a greater distance.

Sometimes changing the direction of the force is more useful than decreasing the force or the distance. For machines that change only the direction of a force—such as the rope system on a flagpole—the input force and output force are the same. Therefore, the mechanical advantage of the machine is 1.

NOTE-TAKING STRATEGY
Remember to organize your notes in a chart or web as you read.

Work transfers energy.

Machines transfer energy to objects on which they do work. Every time you open a door, the doorknob is transferring mechanical energy to the shaft. A machine that lifts an object gives it potential energy. A machine that causes an object to start moving, such as a baseball bat hitting a ball, gives the object kinetic energy.

Energy

When you lift an object, you transfer energy to it in the form of gravitational potential energy—that is, potential energy caused by gravity. The higher you lift an object, the more work you must do and the more energy you give to the object. This is also true if a machine lifts an object. The gravitational potential energy of an object depends on its height above Earth's surface, and it equals the work required to lift the object to that height.

Recall that gravitational potential energy is the product of an object's mass, gravitational acceleration, and height ($GPE = mgh$). In the diagram on page 149, the climber wants to reach the top of the hill. The higher she climbs, the greater her potential energy. This energy comes from the work the climber does. The potential energy she gains equals the amount of work she does.

Work

As you have seen, when you use a machine to do work, there is always an exchange, or tradeoff, between the force you use to do the work and the distance over which you apply that force. You apply less force over a longer distance or greater force over a shorter distance.

To reach the top of the hill, the climber must do work. Because she needs to increase her potential energy by a certain amount, she must do the same amount of work to reach the top of the hill whether she climbs a steep slope or a gentle slope.

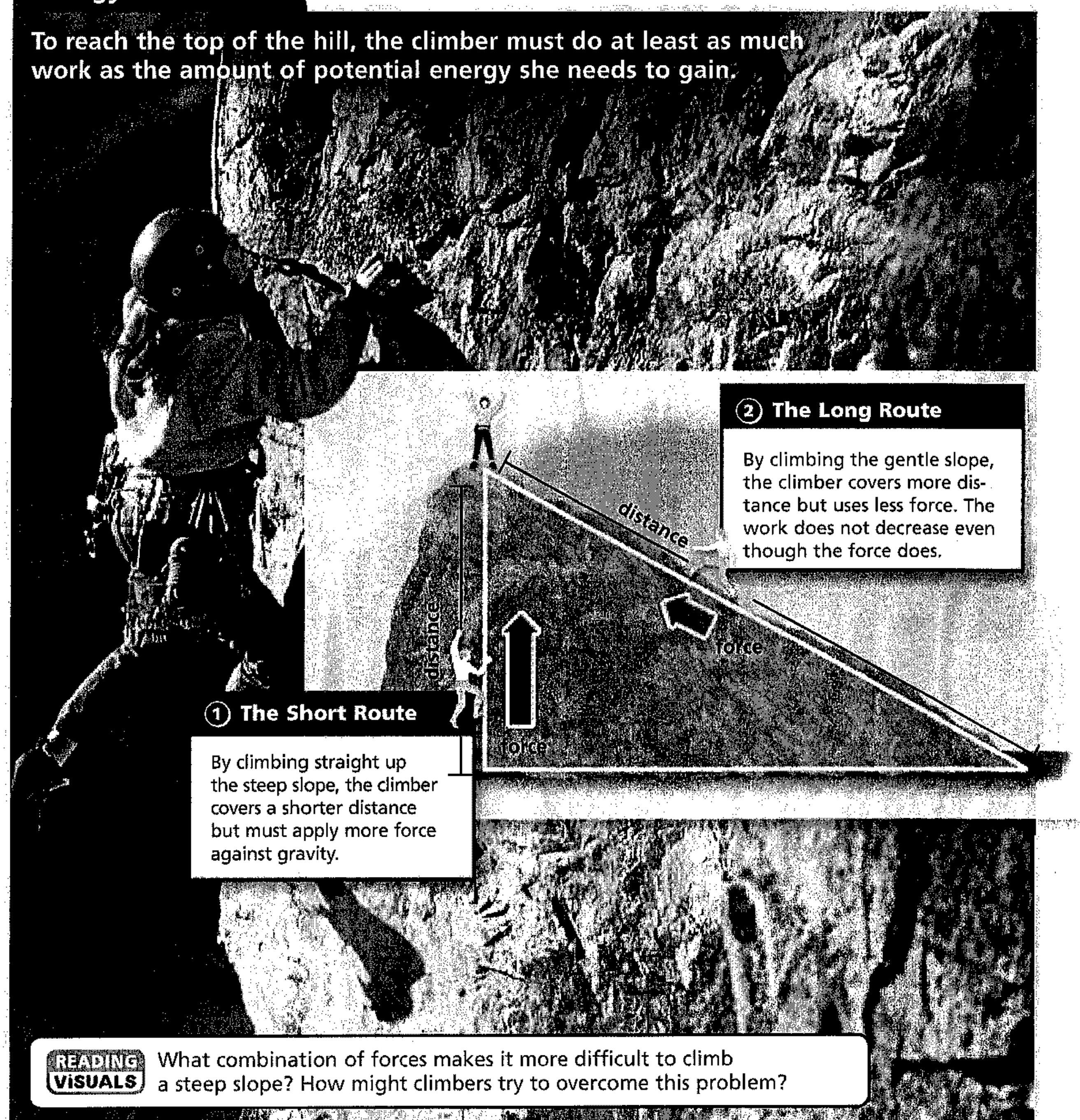
The sloping surface of the hill acts like a ramp, which is a simple machine called an inclined plane. You know that machines make work easier by changing the size or direction of a force. How does this machine make the climber's work easier?

As the climber goes up the hill, she is doing work against gravity.

1. One side of the hill is a very steep slope—almost straight up. If the climber takes the steep slope, she climbs a shorter distance, but she must use more force.
2. Another side of the hill is a long, gentle slope. Here the climber travels a greater distance but uses much less effort.

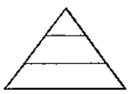
If the climber uses the steep slope, she must lift almost her entire weight. The inclined plane allows her to exert her input force over a longer distance; therefore, she can use just enough force to overcome the net force pulling her down the inclined plane. This force is less than her weight. In many cases, it is easier for people to use less force over a longer distance than it is for them to use more force over a shorter distance.

Energy and Work



Output work is always less than input work.

VOCABULARY
Write your own definition of *efficiency* in a word triangle.



The work you do on a machine is called the input work, and the work the machine does in turn is called the output work. A machine's **efficiency** is the ratio of its output work to the input work. An ideal machine would be 100 percent efficient. All of the input work would be converted to output work. Actual machines lose some input work to friction.

You can calculate the efficiency of a machine by dividing the machine's output work by its input work and multiplying that number by 100.

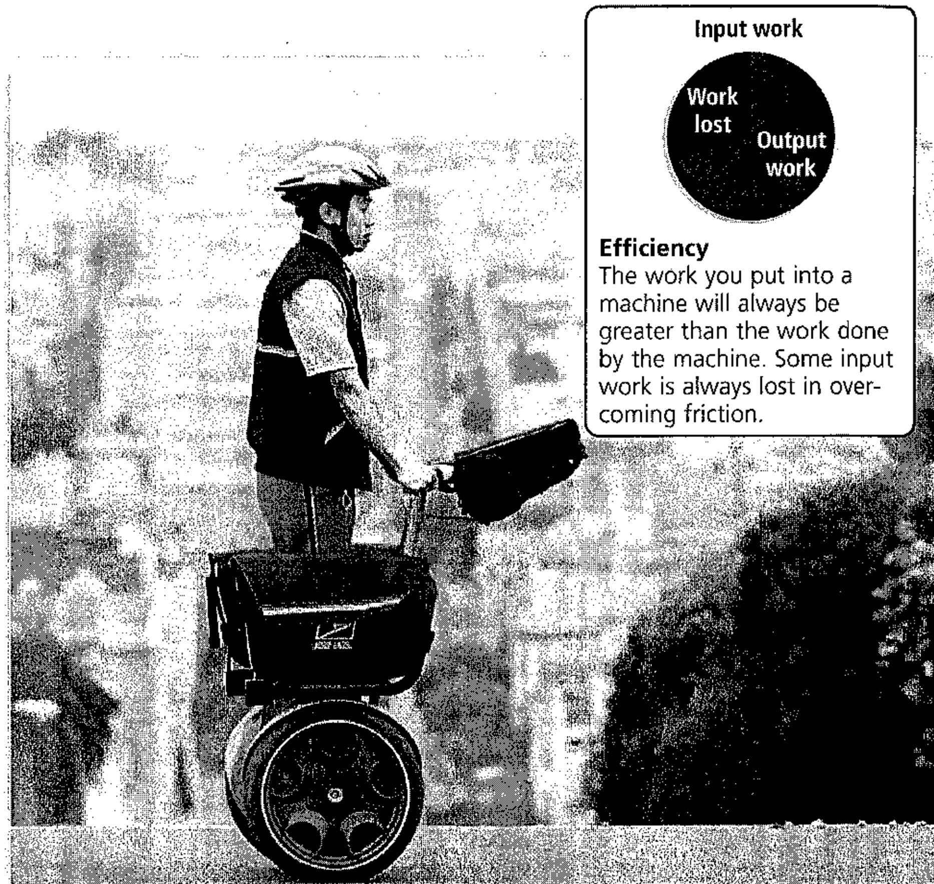
$$\text{Efficiency } (\%) = \frac{\text{Output work}}{\text{Input work}} \cdot 100$$

Recall that work is measured in joules. Suppose you do 600 J of work in using a rope system to lift a box. The work done on the box is 540 J. You would calculate the efficiency of the rope system as follows:

$$\text{Efficiency} = \frac{540\text{ J}}{600\text{ J}} \cdot 100 = 90\%$$

CHECK YOUR READING What is a machine's efficiency? How does it affect the amount of work a machine can do?

APPLY The mail carrier is riding a motorized human transport machine. Suppose the machine has an efficiency of 70 percent. How much work is lost in overcoming friction on the sidewalk and in the motor?



Efficiency
The work you put into a machine will always be greater than the work done by the machine. Some input work is always lost in overcoming friction.

Efficiency and Energy

You know that work transfers energy and that machines make work easier. The more mechanical energy is lost in the transfer to other forms of energy, the less efficient the machine. Machines lose some energy in the form of heat due to friction. The more moving parts a machine has, the more energy it loses to friction because the parts rub together. Machines can lose energy to other processes as well.

For example, a car engine has an efficiency of only about 25 percent. It loses much of the energy supplied by its fuel to heat from combustion. By comparison, a typical electric motor has more than an 80 percent efficiency. That means the motor converts more than 80 percent of the input energy into mechanical energy, or motion.

Many appliances come with energy guides that can help a buyer compare the energy efficiency of different models. A washing machine with the highest energy rating may not always save the most energy, however, because users may have to run those machines more often.

INVESTIGATE Efficiency

What is the efficiency of a ramp?

PROCEDURE

1. Build a ramp as shown. Measure the vertical height of the ramp and the length of the ramp in centimeters. Convert these distances to meters and record.
2. Attach the block to the spring scale and measure the force in newtons needed to lift the block straight up. Record this force as the output force. Multiply the output force by the height of the ramp in meters to get the output work. Record the output work.
3. Use the spring scale to pull the block up the ramp with a constant force. Record the force measured on the spring scale as the input force. Multiply the input force by the length of the ramp in meters to get the input work. Record the input work.
4. Use the input work and output work from steps 2 and 3 to calculate the efficiency of the ramp. Record your results.

WHAT DO YOU THINK?

- How did your input work compare with your output work?
- What could you do to increase the efficiency of the ramp?

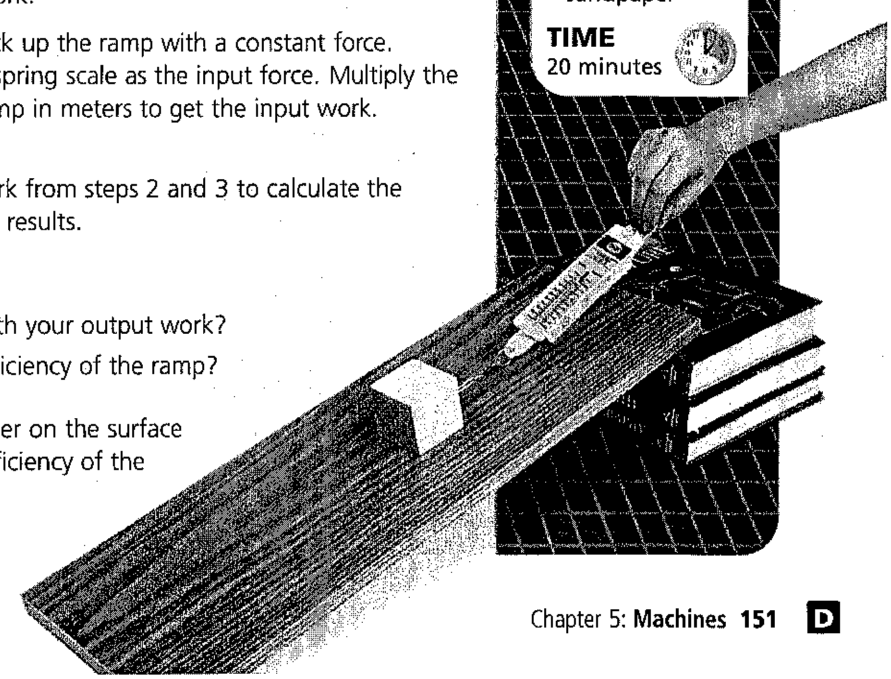
CHALLENGE Would adding sandpaper on the surface of the ramp increase or decrease the efficiency of the ramp? Why? Test your hypothesis.

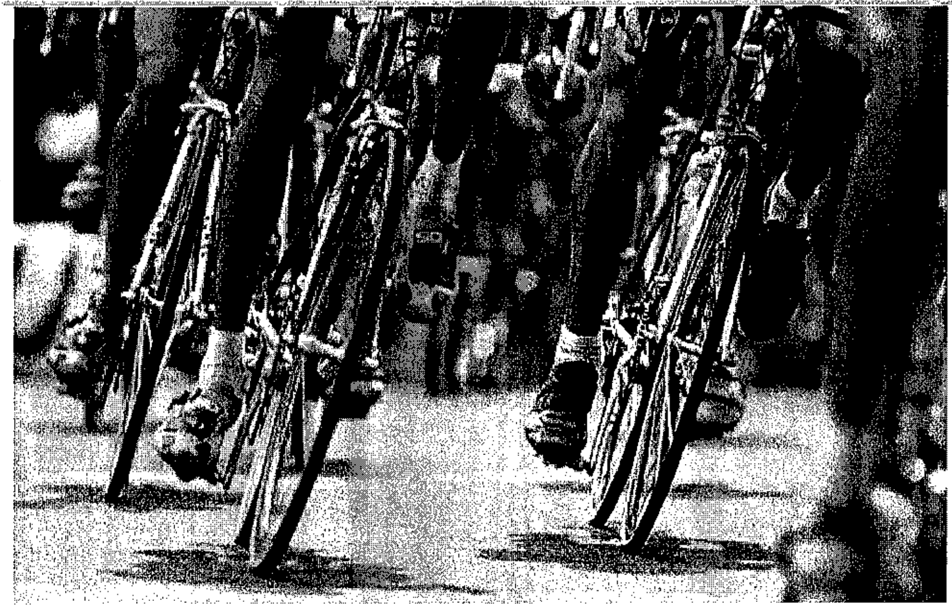
SKILL FOCUS
Analyzing data

MATERIALS
- board
- books
- meter stick
- wooden block with eye hook
- spring scale

for Challenge:
- sandpaper

TIME
20 minutes





Proper maintenance can help keep a bicycle running as efficiently as possible.

Increasing Efficiency

Because all machines lose input work to friction, one way to improve the efficiency of a machine is by reducing friction. Oil is used to reduce friction between the moving parts of car engines. The use of oil makes engines more efficient.

Another machine that loses input work is a bicycle. Bicycles lose energy to friction and to air resistance. Friction losses result from the meeting of the gears, from the action of the chain on the sprocket, and from the tires changing shape against the pavement. A bicycle with poorly greased parts or other signs of poor maintenance requires more force to move. For a mountain bike that has had little maintenance, as much as 15 percent of the total work may be lost to friction. A well-maintained Olympic track bike, on the other hand, might lose only 0.5 percent.

CHECK YOUR READING What is a common way to increase a machine's efficiency?

5.1 Review

KEY CONCEPTS

1. In what ways can a machine change a force?
2. How is a machine's efficiency calculated?
3. Why is a machine's actual output work always less than its input work?

CRITICAL THINKING

4. **Apply** How would the input force needed to push a wheelchair up a ramp change if you increased the height of the ramp but not its length?
5. **Compare** What is the difference between mechanical advantage and efficiency?

CHALLENGE

6. **Apply** Draw and label a diagram to show how to pull down on a rope to raise a load of construction materials.