Can you imagine living in a world with no machines? In this unit, you will explore the scientific meaning of work and learn how machines make work easier. You will find out how energy allows you to do work and how different forms of energy can be converted into other forms of energy. You will also learn about heat and how heating and cooling systems work. This timeline shows some of the inventions and discoveries made throughout history as people have advanced their understanding of work, machines, and energy.

Around 3000 BCE
The sail is used in Egypt. Sails use the wind rather than human power to move boats through the water.

1818
German inventor Baron Karl von Drais de Sauerbrun exhibits the first two-wheeled, rider-propelled machine. Made of wood, this early machine paves the way for the invention of the bicycle.

1948
Maria Telkes, a Hungarian-born physicist, designs the heating system for the first solar-heated house.

1972
The first American self-service gas station opens.
**Around 200 BCE**

Under the Han dynasty, the Chinese become one of the first civilizations to use coal as fuel.

**1656**

Dutch scientist Christiaan Huygens invents the pendulum clock.

**1776**

The American colonies declare their independence from Great Britain.

---

**1893**

The “Clasp Locker,” an early zipper, is patented.

---

**1908**

The automobile age begins with the mass production of the Ford Model T.

---

**1926**

American scientist Robert Goddard launches the first rocket powered by liquid fuel. The rocket reaches a height of 12.5 m and a speed of 97 km/h.

---

**1988**

A wind-powered generator begins generating electrical energy in Scotland’s Orkney Islands.

---

**2000**

The 2000 Olympic Summer Games are held in Sydney, Australia.

---

**2001**

A two-wheeled, battery-powered “people mover” is introduced. Gyroscopes and tilt sensors allow riders to guide the scooter-like transporter by leaning.
### Chapter Planning Guide

#### Work and Machines

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#### Online and Technology Resources

Visit [go.hrw.com](https://go.hrw.com) for access to Holt Online Learning, or enter the keyword **HP7 Home** for a variety of free online resources.

This CD-ROM package includes:
- Lab Materials QuickList Software
- Holt Calendar Planner
- Customizable Lesson Plans
- Printable Worksheets
- ExamView® Test Generator
- Interactive Teacher’s Edition
- Holt PuzzlePro®
- Holt PowerPoint® Resources

**CRF Vocabulary Activity**
**SE Chapter Review, pp. 223–233**
**CRF Chapter Review**
**CRF Chapter Tests**
**SE Standardized Test Preparation, pp. 234–235**
**CRF Standardized Test Preparation**
**CRF Performance-Based Assessment**
**OSP Test Generator, Test Item Listing**

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**KEY**
- CRF: Chapter Resource File
- OSP: One-Stop Planner
- SS: Science Skills Worksheets
- MS: Math Skills for Science Worksheets
- CD or CD-ROM: CD or CD-ROM
- VID: Classroom Video/DVD
- IT: Interactive Textbook
- TR: Transparencies
- LB: Lab Bank
- Requires advance prep
- Also available in Spanish

**Check out Current Science**
Check out Current Science articles and activities by visiting the HRW Web site at go.hrw.com. Just type in the keyword HP5CS08T.

**Classroom Videos**
- Lab Videos demonstrate the chapter lab.
- Brain Food Video Quizzes help students review the chapter material.

**Classroom CD-ROMs**
- Guided Reading Audio CD (Also in Spanish)
- Interactive Explorations
- Virtual Investigations
- Visual Concepts
- Science Tutor

**Holt Lab Generator CD-ROM**
Search for any lab by topic, standard, difficulty level, or time. Edit any lab to fit your needs, or create your own labs. Use the Lab Materials QuickList software to customize your lab materials list.

www.scilinks.org
Maintained by the National Science Teachers Association. See Chapter Enrichment pages that follow for a complete list of topics.

Chapter 8 • Chapter Planning Guide
### Meeting Individual Needs

#### DIRECTED READING A

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**Basic**

**General**

**Also in Spanish**

#### DIRECTED READING B

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**Basic**

**Special Needs**

**Also in Spanish**

### Labs and Activities

#### LONG-TERM PROJECTS & RESEARCH IDEAS

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**Advanced**

**Basic**

**Also in Spanish**

#### WHIZ-BANG DEMONSTRATIONS

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**Advanced**

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#### INQUIRY LABS

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**Advanced**

**Basic**

**Also in Spanish**

#### DATASHEETS FOR QUICK LABS

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**Advanced**

**Basic**

**Also in Spanish**

#### DATASHEETS FOR CHAPTER LABS

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**Advanced**

**Basic**

**Also in Spanish**

#### DATASHEETS FOR LABBOOK

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**Advanced**

**Basic**

**Also in Spanish**

### Review and Assessments

#### SECTION QUIZ

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**General**

**Also in Spanish**

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**General**

**Also in Spanish**

#### CHAPTER REVIEW

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**General**

**Also in Spanish**

#### CHAPTER TEST A

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**Advanced**

**General**

**Also in Spanish**

#### CHAPTER TEST B

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**Advanced**

**General**

**Also in Spanish**

#### CHAPTER TEST C

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**Advanced**

**Special Needs**

**General**

**Also in Spanish**

#### STANDARDIZED TEST PREPARATION

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**General**

**Also in Spanish**

#### PERFORMANCE-BASED ASSESSMENT

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**General**

**Also in Spanish**
Is That a Fact!

Leonardo da Vinci (1452–1519)

Leonardo da Vinci was an Italian painter, sculptor, and inventor. The motivating interest behind all of his work was the appearance of everyday things and the way they operated. He studied the flight of birds, the movement of water, the growth of plants, and the anatomy of the human body.

One of da Vinci’s interests was the mechanical advantage that could be obtained with gears. Da Vinci made drawings of complex machines that were centuries ahead of their time. Among his drawings were plans for tanks, a helicopter, and other aircraft. He was especially concerned with the problems of friction and resistance. He described and drew screws, gears, hydraulic jacks, transmission gears, and swiveling devices.

Da Vinci thought that the basic laws of mechanics operated the same way in all aspects of the world and were the keys to understanding the world and reproducing it through art.

Is That a Fact!

Many industrial towns in early America were located where water flow could be assured all year. Water and wind were the primary sources of mechanical energy until the end of the 18th century, when steam power was developed. Steam-powered mechanical devices launched the Industrial Revolution.

Is That a Fact!

The term horsepower was coined in the late 18th century by Scottish engineer James Watt, who used horses as a measure of power in his experiments. In the English system, 1 horsepower can accomplish 33,000 foot-pounds of work per minute, or allow one to exert the force necessary to lift 33,000 lb by 1 ft in 1 min. This unit was based on the draft horse, a horse adapted for pulling heavy loads.
For background information about teaching strategies and issues, refer to the Professional Reference for Teachers.

Perpetual Motion

- For centuries, inventors have tried to build a perpetual-motion machine—a device that would run forever once it is set in motion. However, no such machines can work because the laws of thermodynamics would be violated.

- A perpetual-motion machine would have to deliver as much or more energy than is put into it. The first law of thermodynamics states that the total energy of a closed system is constant. The second law states that some energy is always lost as thermal energy from a closed system when energy is used to do work. The practical effect of these two laws is that the output energy from any machine will never be as great as the energy put into it.

- Friction—in which kinetic energy is converted to thermal energy—can be reduced but never eliminated. Although some machines can be made to run very efficiently, they will always need a source of energy to operate, and they will never be able to produce more energy than is put into them.

Types of Machines

The Invention of Machines

- The first machines were tools used by prehistoric people to help them hunt and gather food. A wedge shaped out of stone made an excellent cutting tool. Early axes were wedges made of stone. Levers were used in hoes, oars, and slings. Because simple machines multiply force or distance, they provided our early ancestors with a tremendous survival advantage.

The Plow

- The plow was one of the first agricultural machines to be invented, and it is still one of the most important. Evidence shows that plows first appeared more than 6,000 years ago. The first plow was not much more than a digging stick drawn by a person or an animal. As primitive as it was, the plow allowed people to dig deeper to turn over and loosen the soil. This simple machine magnified the effort of a single person enough to produce food for many people.

Is That a Fact!

- Tiny machines are being built with gears and levers so small they can be seen only under a powerful microscope. Scientists are learning how to make even tinier machines out of molecules. Tiny gears have been shaped out of strands of DNA molecules, and hydrogen molecules may one day control microscopic computers.
Overview
This chapter describes the relationship between energy and work, the way machines do work, and the different types of simple and compound machines.

Assessing Prior Knowledge
Students should be familiar with the following topics:
- matter
- forces
- motion

Identifying Misconceptions
As students learn the concepts in this chapter, they will encounter the scientific usage of the word work. Students will need to learn the meaning of work in terms of force applied over a distance instead of in terms of effort expended. Students may also have to overcome the common usage of the word machine, which connotes a large and complicated apparatus, such as a car engine. Students may be slow to consider a simple device, such as a lever, to be a machine.

The Big Idea
Work is the transfer of energy to an object, and power is the rate at which work is done. Machines are devices that help make work easier.

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<td>What Is a Machine?</td>
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<tr>
<td>3</td>
<td>Types of Machines</td>
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About the Photo
“One, two, stroke!” shouts the coach as the team races to the finish line. This paddling team is competing in Hong Kong’s annual Dragon Boat Races. The Dragon Boat Festival is a 2,000-year-old Chinese tradition that commemorates Qu Yuan, a national hero. The paddlers that you see here are using the paddles to move the boat forward. Even though they are celebrating by racing their dragon boat, in scientific terms, this team is doing work.

PRE-READING Activity
Booklet
Before you read the chapter, create the FoldNote entitled “Booklet” described in the Study Skills section of the Appendix. Label each page of the booklet with a main idea from the chapter. As you read the chapter, write what you learn about each main idea on the appropriate page of the booklet.

Standards Correlations
National Science Education Standards
The following codes indicate the National Science Education Standards that correlate to this chapter. The full text of the standards is at the front of the book.

<table>
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<td>Section 2 What Is a Machine?</td>
<td>UCP 3, SAI 1, 2, ST 2</td>
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<tr>
<td>Section 3 Types of Machines</td>
<td>UCP 3, 5, SAI 1, ST 1, 2, LabBook: SAI 1</td>
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<td>SAI 1, 2, PS 3a, ST 2</td>
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<td>Science in Action</td>
<td>SAI 1, 2</td>
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In this activity, you will use a simple machine, a lever, to make your task a little easier.

**Procedure**

1. Stack **two books**, one on top of the other, on a table.
2. Slide your index finger underneath the edge of the bottom book. Using only the force of your finger, try to lift one side of the books 2 or 3 cm off the table. Is it hard to do so? Write your observations.
3. Slide the end of a **wooden ruler** underneath the edge of the bottom book. Then, slip a **large pencil eraser** or similar object under the ruler.

**Analysis**

1. Which was easier: lifting the books with your finger or lifting the books with the ruler? Explain your answer.
2. In what way did the direction of the force that your finger applied on the books differ from the direction of the force that your finger applied on the ruler?

**Answers**

1. Students should find that lifting the books with the ruler was easier because less effort (force) was required.
2. The direction of the force applied by students’ fingers on the books was up, and the direction of the force applied on the ruler was down. Using the ruler changed the direction of the force.
Work and Power

Your science teacher has just given you tonight's homework assignment. You have to read an entire chapter by tomorrow! That sounds like a lot of work!

Actually, in the scientific sense, you won't be doing much work at all! How can that be? In science, work is done when a force causes an object to move in the direction of the force. In the example above, you may have to put a lot of mental effort into doing your homework, but you won't be using force to move anything. So, in the scientific sense, you will not be doing work—except the work to turn the pages of your book!

What Is Work?

The student in Figure 1 is having a lot of fun, isn’t she? But she is doing work, even though she is having fun. She is doing work because she is applying a force to the bowling ball and making the ball move through a distance. However, she is doing work on the ball only as long as she is touching it. The ball will keep moving away from her after she releases it. But she will no longer be doing work on the ball because she will no longer be applying a force to it.

Transfer of Energy

One way you can tell that the bowler in Figure 1 has done work on the bowling ball is that the ball now has kinetic energy. This means that the ball is now moving. The bowler has transferred energy to the ball.

Differences Between Force and Work

Applying a force doesn’t always result in work being done. Suppose that you help push a stalled car. You push and push, but the car doesn’t budge. The pushing may have made you tired. But you haven’t done any work on the car, because the car hasn’t moved.

You do work on the car as soon as the car moves. Whenever you apply a force to an object and the object moves in the direction of the force, you have done work on the object.

Answer to Reading Check

No, work is done on an object only if force makes the object move in a direction that is parallel to the force.
Force and Motion in the Same Direction

Suppose you are in the airport and late for a flight. You have to run through the airport carrying a heavy suitcase. Because you are making the suitcase move, you are doing work on it, right? Wrong! For work to be done on an object, the object must move in the same direction as the force. You are applying a force to hold the suitcase up, but the suitcase is moving forward. So, no work is done on the suitcase. But work is done on the suitcase when you lift it off the ground.

Work is done on an object if two things happen: (1) the object moves as a force is applied and (2) the direction of the object’s motion is the same as the direction of the force. The pictures and arrows in Figure 2 will help you understand when work is being done on an object.

Example Direction of force Direction of motion Doing work?
---
Example 1: Upward force, upward motion Yes
Example 2: Upward force, downward motion No
Example 3: Downward force, downward motion Yes
Example 4: Downward force, upward motion No

Work: the transfer of energy to an object by using a force that causes the object to move in the direction of the force.

Work and the Direction of Force

You may not be doing any work on a suitcase if you are just holding it in your hands, but your body will still get tired from the effort because you are doing work on the muscles inside your body. Your muscles can contract thousands of times in just a few seconds while you try to keep the suitcase from falling. What other situations can you think of that might involve work being done somewhere inside your body? Describe these situations in your science journal.

MISCONCEPTION ALERT

Work and Force  The text states that the girl does work on the bowling ball only when she is touching it. The ball continues to move when she lets go of it, but she’s no longer applying a force to it. Disregarding friction, once the ball is moving, no additional force is needed to keep it moving at constant speed because of Newton’s first law of motion.

Support for English Language Learners

Work and the Direction of Force  Students will better understand when work is being performed if they create their own examples. After they have read the text and chart on these pages, review the examples in the chart as a class. Ask volunteers to point out where work is being done and why. Then, have each student create a similar chart with four of their own examples from their everyday lives, including sports and games. They should draw each example, specify direction of force and motion with arrows, and indicate whether or not work is being done. Emphasize to students that they should not just copy the information from the chart in the text. When charts are completed, ask students to exchange charts and look for any misconceptions about work. Discuss these in class.

Logical
How Much Work?

Would you do more work on a car by pushing it up a long road to reach the top of a hill or by using a cable to raise the car up the side of a cliff to the top of the same hill? You would certainly need a different amount of force. Common use of the word "work" may make it seem that there would be a difference in the amount of work done in the two cases as well.

Figure 3 For each path, the same work is done to move the car to the top of the hill, although distance and force along the two paths differ.

Same Work, Different Forces

You may be surprised to learn that the same amount of work is being done to push the car up a road as to raise it up the cliff. Look at Figure 3. A certain amount of energy is needed to move the car from the bottom to the top of the hill. Because the car ends up at the same place either way, the work done on the car is the same. However, pushing the car along the road up a hill seems easier than lifting it straight up. Why?

The reason is that work depends on distance as well as force. Consider a mountain climber who reaches the top of a mountain by climbing straight up a cliff, as in Figure 4. She must use enough force to overcome her entire weight. But the distance she travels up the cliff is shorter than the distance traveled by hikers who reach the top of the same mountain by walking up a slope. Either way, the same amount of work is done. But the hikers going up a slope don’t need to use as much force as if they were going straight up the side of the cliff. This shows how you can use less force to do the same amount of work.

Figure 4 Climbers going to the top of a mountain do the same amount of work whether they hike up a slope or go straight up a cliff.

Activity

Work Done on a Spring Scale Obtain a meter stick, string, a spring scale, and various objects to lift. Organize students into pairs. Have each pair attach each object in turn to the spring scale and slowly lift or pull the object and then record how much force was used. Next, have them measure the distance that the object moved and record the distance in meters. Have them calculate how much work was done.
Calculating Work
The amount of work \((W)\) done in moving an object, such as the barbell in Figure 5, can be calculated by multiplying the force \((F)\) applied to the object by the distance \((d)\) through which the force is applied, as shown in the following equation:

\[
W = F \times d
\]

Force is expressed in newtons, and the meter is the basic SI unit for length or distance. Therefore, the unit used to express work is the newton-meter \((N \times m)\), which is more simply called the joule. Because work is the transfer of energy to an object, the joule \((J)\) is also the unit used to measure energy.

Reading Check  How is work calculated?

\[W = 80 \text{ N} \times 1 \text{ m} = 80 \text{ J}\]
The force needed to lift an object is equal to the gravitational force on the object—in other words, the object’s weight.

\[W = 160 \text{ N} \times 1 \text{ m} = 160 \text{ J}\]
If you increase the weight, an increased force is needed to lift the object. This increases the amount of work done.

\[W = 80 \text{ N} \times 2 \text{ m} = 160 \text{ J}\]
Increasing the distance also increases the amount of work done.

Quick Lab
Get to Work!
1. Use a loop of string to attach a spring scale to a weight.
2. Slowly pull the weight across a table by dragging the spring scale. Record the amount of force that you exerted on the weight.
3. Use a metric ruler to measure the distance that you pulled the weight.
4. Now, use the spring scale to slowly pull the weight up a ramp. Pull the weight the same distance that you pulled it across the table.
5. Calculate the work you did on the weight for both trials.
6. How were the amounts of work and force affected by the way you pulled the weight? What other ways of pulling the weight could you test?

Answer to Reading Check
Work is calculated as force times distance.

Teacher’s Note: Be sure that students pull the weight with a constant speed. They should also keep the spring scale parallel to the tabletop or ramp when pulling.

Answer
6. Sample answer: More force was needed to pull the weight across the ramp than to pull it across the table. Therefore, more work was done when pulling the weight across the ramp. Other ways of pulling the weight might include using a much steeper ramp or pulling the weight straight up a vertical surface.

Science Humor
Q: Did you hear about the criminals who never had to do any work?
A: They were joule thieves.

Chapter Resources
Technology
- Transparencies
  - P30 Force Times Distance
Workbooks
- Math Skills for Science
  - Work and Power General
Power: How Fast Work Is Done

Like the term work, the term power is used a lot in everyday language but has a very specific meaning in science. Power is the rate at which energy is transferred.

Calculating Power

To calculate power \( P \), you divide the amount of work done \( W \) by the time \( t \) it takes to do that work, as shown in the following equation:

\[
P = \frac{W}{t}
\]

The unit used to express power is joules per second (J/s), also called the watt. One watt (W) is equal to 1 J/s. So if you do 50 J of work in 5 s, your power is 10 J/s, or 10 W.

Power measures how fast work happens, or how quickly energy is transferred. When more work is done in a given amount of time, the power output is greater. Power output is also greater when the time it takes to do a certain amount of work is decreased, as shown in Figure 6.

Figure 6 No matter how fast you can sand by hand, an electric sander can do the same amount of work faster. Therefore, the electric sander has more power.

More Power to You A stage manager at a play raises the curtain by doing 5,976 J of work on the curtain in 12 s. What is the power output of the stage manager?

Step 1: Write the equation for power.

\[P = \frac{W}{t}\]

Step 2: Replace \( W \) and \( t \) with work and time.

\[P = \frac{5,976 \text{ J}}{12 \text{ s}} = 498 \text{ W}\]

Now It’s Your Turn

1. If it takes you 10 s to do 150 J of work on a box to move it up a ramp, what is your power output?

2. A light bulb is on for 12 s, and during that time it uses 1,200 J of electrical energy. What is the wattage (power) of the light bulb?

Answer to Reading Check

How is power calculated?

Answers to Math Focus

1. \( \frac{150 \text{ J}}{10 \text{ s}} = 15 \text{ W} \)
2. \( \frac{1,200 \text{ J}}{12 \text{ s}} = 100 \text{ W} \)
Increasing Power

It may take you longer to sand a wooden shelf by hand than by using an electric sander, but the amount of energy needed is the same either way. Only the power output is lower when you sand the shelf by hand (although your hand may get more tired). You could also dry your hair with a fan, but it would take a long time! A hair dryer is more powerful. It can give off energy more quickly than a fan does, so your hair dries faster.

Car engines are usually rated with a certain power output. The more powerful the engine is, the more quickly the engine can move a car. And for a given speed, a more powerful engine can move a heavier car than a less powerful engine can.

**Summary**

- In scientific terms, work is done when a force causes an object to move in the direction of the force.
- Work is calculated as force times distance. The unit of work is the newton-meter, or joule.
- Power is a measure of how fast work is done.
- Power is calculated as work divided by time. The unit of power is the joule per second, or watt.

**Understanding Key Ideas**

3. How is work calculated?
   - a. force times distance
   - b. force divided by distance
   - c. power times distance
   - d. power divided by distance

4. What is the difference between work and power?

**Using Key Terms**

For each pair of terms, explain how the meanings of the terms differ.

1. work and joule
2. power and watt

**Math Skills**

5. Using a force of 10 N, you push a shopping cart 10 m. How much work did you do?
6. If you did 100 J of work in 5 s, what was your power output?

**Critical Thinking**

7. Analyzing Processes Work is done on a ball when a pitcher throws it. Is the pitcher still doing work on the ball as it flies through the air? Explain.

8. 50 N x 0.5 m = 25 J; No further work has been done on the chair once it has been lifted, because the direction in which you walk is perpendicular to the direction in which you lifted the chair.

9. The diagram describes the fact that for either path taken, the same work is done on an object, although distance and force between the two paths vary.

**Answers to Section Review**

1. Sample answer: Work occurs when a force causes an object to move in the direction of the force. Joule is the unit in which work is measured.

2. Sample answer: Power is the rate at which work is done. Watt is the unit in which power is measured.

3. a. Sample answer: Power is the rate at which work is done. And for a given speed, a more powerful engine can move a heavier car than a less powerful engine can.

4. Work is done when a force causes an object to move in the direction of the force, and power is the rate at which work is done.

5. 10 N x 10 m = 100 J
6. 100 J / 5 s = 20 W

7. no; Once the ball leaves the pitcher’s hand, work is no longer being done on the ball. The motion of the ball after that point is due to the kinetic energy already given to the ball by the pitcher.

8. 50 N x 0.5 m = 25 J; No further work has been done on the chair once it has been lifted, because the direction in which you walk is perpendicular to the direction in which you lifted the chair.

9. The diagram describes the fact that for either path taken, the same work is done on an object, although distance and force between the two paths vary.
What Is a Machine?

You are in the car with your mom on the way to a party when suddenly—KABLOOM hiss— a tire blows out. “Now I’m going to be late!” you think as your mom pulls over to the side of the road.

You watch as she opens the trunk and gets out a jack and a tire iron. Using the tire iron, she pries the hubcap off and begins to unscrew the lug nuts from the wheel. She then puts the jack under the car and turns the jack’s handle several times until the flat tire no longer touches the ground. After exchanging the flat tire with the spare, she lowers the jack and puts the lug nuts and hubcap back on the wheel.

“Wow!” you think, “That wasn’t as hard as I thought it would be.” As your mom drops you off at the party, you think how lucky it was that she had the right equipment to change the tire.

Machines: Making Work Easier

Now, imagine changing a tire without the jack and the tire iron. Would it have been easy? No, you would have needed several people just to hold up the car! Sometimes, you need the help of machines to do work. A machine is a device that makes work easier by changing the size or direction of a force.

When you think of machines, you might think of things such as cars, big construction equipment, or even computers. But not all machines are complicated. In fact, you use many simple machines in your everyday life. Figure 1 shows some examples of machines.

Figure 1  Some Everyday Machines

Scissors
Chopsticks
Wheelchair

Connection Activity

Home Economics—GENERAL

Kitchen Utensils as Machines  Show students some common kitchen utensils, such as knives, forks, can and bottle openers, nutcrackers, and manual eggbeaters. Allow students to examine the utensils and discuss their uses. Then, have students speculate how each machine makes work easier.
Work In, Work Out
Suppose that you need to get the lid off a can of paint. What do you do? One way to pry the lid off is to use a common machine known as a lever. Figure 2 shows a screwdriver being used as a lever. You place the tip of the screwdriver under the edge of the lid and then push down on the screwdriver's handle. The tip of the screwdriver lifts the lid as you push down. In other words, you do work on the screwdriver, and the screwdriver does work on the lid.

Work is done when a force is applied through a distance. Look again at Figure 2. The work that you do on a machine is called work input. You apply a force, called the input force, to the machine through a distance. The work done by the machine on an object is called work output. The machine applies a force, called the output force, through a distance.

How Machines Help
You might think that machines help you because they increase the amount of work done. But that’s not true. If you multiplied the forces by the distances through which the forces are applied in Figure 2 (remember that \( W = F \times d \)), you would find that the screwdriver does not do more work on the lid than you do on the screwdriver. Work output can never be greater than work input. Machines allow force to be applied over a greater distance, which means that less force will be needed for the same amount of work.

Answer to Reading Check
Machines make work easier by allowing force to be applied over a greater distance.
Machines make work easier by changing the size or direction (or both) of the input force. When a screwdriver is used as a lever to open a paint can, both the size and direction of the input force change. Remember that using a machine does not change the amount of work you will do. As Figure 3 shows, the same amount of work is done with or without the ramp. The ramp decreases the size of the input force needed to lift the box but increases the distance over which the force is exerted. So, the machine allows a smaller force to be applied over a longer distance.

The Force-Distance Trade-Off
When a machine changes the size of the force, the distance through which the force is exerted must also change. Force or distance can increase, but both cannot increase. When one increases, the other must decrease.

Figure 4 shows how machines change force and distance. Whenever a machine changes the size of a force, the machine also changes the distance through which the force is applied. Figure 4 also shows that some machines change only the direction of the force, not the size of the force or the distance through which the force is exerted.

Reading Check What are the two things that a machine can change about how work is done?

Lifting this box straight up requires an input force equal to the weight of the box.

Using a ramp to lift the box requires an input force less than the weight of the box, but the input force must be exerted over a greater distance than if you didn’t use a ramp.

W = 450 N × 1 m = 450 J
W = 150 N × 3 m = 450 J

Graphing Force and Distance
A certain task takes 480 J of work. Remind students that many combinations of F × d result in 480 J of work (480 N × 1 m or 64 N × 7.5 m). Help students find combinations of forces and distances whose products are 480 J. Have them use these number pairs to plot and connect points on a graph (with F on the x-axis and d on the y-axis). Discuss what the graphs show about the relationship between force and distance. (F and d are inversely related.) Students can start with any two of the quantities, calculate the third, and then make the graph.

Homework

Everyday Use of Machines Have students keep a “machine diary” for a week. Each day, they should describe the machines they used or came into contact with over the course of the day. Have them expand their ideas of what a machine is by examining ordinary actions such as writing or playing and deciding whether a machine is involved.

Answer to Reading Check Machines can change the force or the distance through which force is applied.
Mechanical Advantage

Some machines make work easier than others do because they can increase force more than other machines can. A machine's mechanical advantage is the number of times the machine multiplies force. In other words, the mechanical advantage compares the input force with the output force.

Calculating Mechanical Advantage

You can find mechanical advantage by using the following equation:

\[
\text{mechanical advantage (MA)} = \frac{\text{output force}}{\text{input force}}
\]

For example, imagine that you had to push a 500 N weight up a ramp and only needed to push with 50 N of force the entire time. The mechanical advantage of the ramp would be calculated as follows:

\[
MA = \frac{500 \text{ N}}{50 \text{ N}} = 10
\]

A machine that has a mechanical advantage that is greater than 1 can help move or lift heavy objects because the output force is greater than the input force. A machine that has a mechanical advantage that is less than 1 will reduce the output force but can increase the distance an object moves. Figure 4 shows an example of such a machine—a hammer.

Finding the Advantage

A grocer uses a handcart to lift a heavy stack of canned food. Suppose that he applies an input force of 40 N to the handcart. The cart applies an output force of 320 N to the stack of canned food. What is the mechanical advantage of the handcart?

\[
MA = \frac{320 \text{ N}}{40 \text{ N}} = 8
\]

Math Practice

Answers to Math Practice

MA = 320 N ÷ 40 N = 8

Animals Using Tools

Humans aren’t the only animals that use tools. Chimpanzees fashion specialized twigs to snare termites from inside their mounds, and some otters use carefully selected rocks to crack open shellfish. The use of tools is considered a distinct evolutionary advantage. Have students find information about such tool use and make some creative presentations to the class. Verbal

SUPPORT FOR

English Language Learners

Machines and Force

Visual aids may help students understand the different effects machines can have on force. Provide pairs of students pictures of several types of machines, such as those used in construction or industry. Draw a two-circle Venn diagram on the board, and label the circles size and direction. Have one student from each pair copy the diagram onto a sheet of paper. Ask students to analyze whether each machine changes the size or the direction (or both) of a force, and tape the picture in the correct place on the diagram. Remind students that machines affecting both size and direction of forces should be placed in the circles’ overlap. When students have finished, ask them to show their diagrams to the class and briefly explain their reasons for placements. Visual/Logical

Prehistoric Machines

Have students research prehistoric uses of machines, especially the earliest occurrences of machines that change the size or direction of a force in the same ways that the examples in Figure 4 do. Logical

Answers to Math Practice

MA = 320 N ÷ 40 N = 8
Mechanical Efficiency

The work output of a machine can never be greater than the work input. In fact, the work output of a machine is always less than the work input. Why? Some of the work done by the machine is used to overcome the friction created by the use of the machine. But keep in mind that no work is lost. The work output plus the work done to overcome friction is equal to the work input.

The less work a machine has to do to overcome friction, the more efficient the machine is.

Mechanical efficiency is a comparison of a machine’s work output with the work input.

Calculating Efficiency

A machine’s mechanical efficiency is calculated using the following equation:

\[ \text{mechanical efficiency} = \left( \frac{\text{work output}}{\text{work input}} \right) \times 100 \]

The 100 in this equation means that mechanical efficiency is expressed as a percentage. Mechanical efficiency tells you what percentage of the work input gets converted into work output.

Figure 5 shows a machine that is used to drill holes in metal. Some of the work input is used to overcome the friction between the metal and the drill. This energy cannot be used to do work on the steel block. Instead, it heats up the steel and the machine itself.

Reading Check

How is mechanical efficiency calculated?
**Perfect Efficiency?**

An *ideal machine* would be a machine that had 100% mechanical efficiency. An ideal machine’s useful work output would equal the work done on the machine. Ideal machines are impossible to build, because every machine has moving parts. Moving parts always use some of the work input to overcome friction. But new technologies help increase efficiency so that more energy is available to do useful work. The train in **Figure 6** is floating on magnets, so there is almost no friction between the train and the tracks. Other machines use lubricants, such as oil or grease, to lower the friction between their moving parts, which makes the machines more efficient.

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**Summary**

- A machine makes work easier by changing the size or direction (or both) of a force.
- A machine can increase force or distance, but not both.
- Mechanical advantage tells how many times a machine multiplies force.
- Mechanical efficiency is a comparison of a machine’s work output with work input.
- Machines are not 100% efficient because some of the work done is used to overcome friction.

**Using Key Terms**

For each pair of terms, explain how the meanings of the terms differ.

1. work input and work output
2. mechanical advantage and mechanical efficiency

**Understanding Key Ideas**

3. Which of the following is the correct way to calculate mechanical advantage?
   a. input force ÷ output force
   b. output force ÷ input force
   c. work input ÷ work output
   d. work output ÷ work input

4. Explain how using a ramp makes work easier.

5. Give a specific example of a machine, and describe how its mechanical efficiency might be calculated.

6. Why can’t a machine be 100% efficient?

**Math Skills**

7. Suppose that you exert 60 N on a machine and the machine exerts 300 N on another object. What is the machine’s mechanical advantage?

8. What is the mechanical efficiency of a machine whose work input is 100 J and work output is 30 J?

**Critical Thinking**

9. Making Inferences For a machine with a mechanical advantage of 3, how does the distance through which the output force is exerted differ from the distance through which the input force is exerted?

10. Analyzing Processes Describe the effect that friction has on a machine’s mechanical efficiency. How do lubricants increase a machine’s mechanical efficiency?

---

**Answers to Section Review**

1. Sample answer: Work input is the work done on a machine. Work output is the work done by a machine.

2. Sample answer: Mechanical advantage is the number of times a machine multiplies force. Mechanical efficiency measures the ratio of work output to work input.

3. b

4. A ramp allows you to lift something by pushing it a longer distance using less force.

5. Sample answer: an elevator; Its work output could be measured by the weight and distance a load is carried upward, and its work input could be measured by the electrical energy it uses to do that work. You would then divide the work output by the work input and multiply by 100 to get a percentage: the mechanical efficiency.

6. Machines have moving parts in which friction causes energy input to be lost as heat.

7. \( MA = \frac{300 \text{ N}}{60 \text{ N}} = 5 \)

8. \( ME = \frac{(30 \text{ J} + 100 \text{ J})}{100} = 30\% \)

9. Sample answer: The output force would be applied through a distance one-third that of the distance that the input force is applied.

10. Sample answer: Lubricants decrease the friction in a machine, thereby allowing more of the work input to be converted to work output.
Overview
This section describes the six simple machines and explains how to determine the mechanical advantage of each. Students learn about compound machines and combinations of simple machines they commonly encounter, and they learn how combining simple machines affects efficiency.

Bellringer
Pose the following question to students: What type of machine can be found on at least half the students in this room right now? (zipper)

Motivate

Activity

Loads on a First-Class Lever
Organize the class into small groups. Have each group use a string to hang a meterstick from a ring. The meterstick should be balanced until it hangs level. Then, ask the groups to tie five large metal washers tied together to the meterstick at the 2 cm mark. Challenge them to find a way to again balance the meterstick without adding any weights to the opposite end. Discuss the students’ solutions to the problem. 

Types of Machines
Imagine that it’s a hot summer day. You have a whole ice-cold watermelon in front of you. It would taste cool and delicious—if only you had a machine that could cut it!

The machine you need is a knife. But how is a knife a machine? A knife is actually a very sharp wedge, which is one of the six simple machines. The six simple machines are the lever, the inclined plane, the wedge, the screw, the pulley, and the wheel and axle. All machines are made from one or more of these simple machines.

Levers
Have you ever used the claw end of a hammer to remove a nail from a piece of wood? If so, you were using the hammer as a lever. A lever is a simple machine that has a bar that pivots at a fixed point, called a fulcrum. Levers are used to apply a force to a load. There are three classes of levers, which are based on the placements of the fulcrum, the load, and the input force.

First-Class Levers
With a first-class lever, the fulcrum is between the input force and the load, as shown in Figure 1. First-class levers always change the direction of the input force. And depending on the location of the fulcrum, first-class levers can be used to increase force or to increase distance.

When the fulcrum is closer to the load than to the input force, the lever has a mechanical advantage of greater than 1. The output force is increased because it is exerted over a shorter distance.

When the fulcrum is exactly in the middle, the lever has a mechanical advantage of 1. The output force is not increased because the input force’s distance is not increased.

When the fulcrum is closer to the input force than to the load, the lever has a mechanical advantage of less than 1. Although the output force is less than the input force, distance increases.
In a **second-class lever**, the output force, or load, is between the input force and the fulcrum. Using a second-class lever results in a mechanical advantage of greater than 1. The closer the load is to the fulcrum, the more the force is increased and the greater the mechanical advantage is.

**Second-Class Levers**
The load of a second-class lever is between the fulcrum and the input force, as shown in **Figure 2**. Second-class levers do not change the direction of the input force. But they allow you to apply less force than the force exerted by the load. Because the output force is greater than the input force, you must exert the input force over a greater distance.

**Third-Class Levers**
The input force in a third-class lever is between the fulcrum and the load, as shown in **Figure 3**. Third-class levers do not change the direction of the input force. In addition, they do not increase the input force. Therefore, the output force is always less than the input force.

**Reading Check** How do the three types of levers differ from one another? (See the Appendix for answers to Reading Checks.)

**Figure 2 Examples of Second-Class Levers**

![Second-Class Lever Diagram]

**Figure 3 Examples of Third-Class Levers**

![Third-Class Lever Diagram]

**Brain Food**

**Levers** Besides being used in bottle openers and nail pullers, levers are used in devices such as fishing rods, cranes, typewriters, pianos, parking meters, and scales.

**Is That a Fact?**
The human body uses simple machines. Muscles and bones form first-class and third-class levers. When you look up, the skull pivots on the neck vertebrae, forming a first-class lever. When you kick a soccer ball, the contracting muscle pulls your leg upward, acting as a third-class lever.

**Making Models**

**Seesaws as First-Class Levers**
Provide students with triangular blocks and long pieces of wood so that they can make small seesaws. Have students experiment with the position and size of the weights and the placement of the fulcrum. Have them write their observations and descriptions in their science journal.

**Classifying Tools**
Gather a selection of levers, such as brooms, shovels, crowbars, fishing poles, ice or sugar-cube tongs, pliers, scissors, baseball bats, tennis rackets, hockey sticks, golf clubs, canoe paddles, boat oars, wheelbarrows, nutcrackers, tweezers, and bottle openers. Divide the class into groups, and assign each group several tools. Have each group work together to locate the fulcrum, load, location of input force, and location of output force in each lever. Then, have each group share its information with other groups.

**Answer to Reading Check**
Each class of lever involves a different set of mechanical-advantage possibilities.
Pulleys

When you open window blinds by pulling on a cord, you’re using a pulley. A pulley is a simple machine that has a grooved wheel that holds a rope or a cable. A load is attached to one end of the rope, and an input force is applied to the other end. Types of pulleys are shown in Figure 4.

**Fixed Pulleys**

A fixed pulley is attached to something that does not move. By using a fixed pulley, you can pull down on the rope to lift the load up. The pulley changes the direction of the force. Elevators make use of fixed pulleys.

**Movable Pulleys**

Unlike fixed pulleys, movable pulleys are attached to the object being moved. A movable pulley does not change a force’s direction. Movable pulleys do increase force, but they also increase the distance over which the input force must be exerted.

**Block and Tackles**

When a fixed pulley and a movable pulley are used together, the pulley system is called a block and tackle. The mechanical advantage of a block and tackle depends on the number of rope segments.

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**Figure 4  Types of Pulleys**

- **Fixed Pulley**: A fixed pulley only spins. The size of the output force is the same as the size of the input force. Therefore, a fixed pulley provides a mechanical advantage of 1.

- **Movable Pulley**: A movable pulley moves up with the load as the load is lifted. The mechanical advantage of this movable pulley is 2.

- **Block and Tackle**: The mechanical advantage of this block and tackle is 4 because there are four rope segments. It multiplies your input force by 4, but you have to pull the rope 4 m just to lift the load 1 m.

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**Guided Practice**

**Simple Machines Collage** Collect some old magazines. After students have read the section on simple machines, have them look through the magazines for pictures of different types of simple machines. Have students make a collage that classifies the pictures according to the type of simple machine they represent.

**Real World**

**Machines in Your School** Take students to visit the custodian’s area in the school building. Have the custodian demonstrate the uses of different machines, and discuss how machines make the necessary tasks of maintaining the school building easier.
Wheel and Axle
Did you know that a faucet is a machine? The faucet shown in Figure 5 is an example of a wheel and axle, a simple machine consisting of two circular objects of different sizes. Doorknobs, wrenches, and steering wheels all use a wheel and axle. Figure 5 shows how a wheel and axle works.

Mechanical Advantage of a Wheel and Axle
The mechanical advantage of a wheel and axle can be found by dividing the radius (the distance from the center to the edge) of the wheel by the radius of the axle, as shown in Figure 6. Turning the wheel results in a mechanical advantage of greater than 1 because the radius of the wheel is larger than the radius of the axle.

Reading Check How is the mechanical advantage of a wheel and axle calculated?

Answer to Reading Check
The mechanical advantage of a wheel and axle is the radius of the wheel divided by the radius of the axle.
**Mechanical Advantage of an Inclined Plane**

A heavy box is pushed up a ramp that has an incline of 4.8 m long and 1.2 m high. What is the mechanical advantage of the ramp?

**Step 1:** Write the equation for the mechanical advantage of an inclined plane.

\[ MA = \frac{l}{h} \]

**Step 2:** Replace \( l \) and \( h \) with length and height.

\[ MA = \frac{4.8}{1.2} = 4 \]

**Now It’s Your Turn**

1. A wheelchair ramp is 9 m long and 1.5 m high. What is the mechanical advantage of the ramp?
2. As a pyramid is built, a stone block is dragged up a ramp that is 120 m long and 20 m high. What is the mechanical advantage of the ramp?
3. If an inclined plane were 2 m long and 8 m high, what would be its mechanical advantage?
Wedges

Imagine trying to cut a melon in half with a spoon. It wouldn’t be easy, would it? A knife is much more useful for cutting because it is a **wedge**. A wedge is a pair of inclined planes that move. A wedge applies an output force that is greater than your input force, but you apply the input force over a greater distance. For example, a knife is a common wedge that can easily cut into a melon and push apart its two halves, as shown in Figure 8. Other useful wedges include doorstops, plows, ax heads, and chisels.

**Mechanical Advantage of Wedges**

The longer and thinner the wedge is, the greater its mechanical advantage is. That’s why axes and knives cut better when you sharpen them—you are making the wedge thinner. Therefore, less input force is required. The mechanical advantage of a wedge can be found by dividing the length of the wedge by its greatest thickness, as shown in Figure 8.

**Screws**

A **screw** is an inclined plane that is wrapped in a spiral around a cylinder, as you can see in Figure 9. When a screw is turned, a small force is applied over the long distance along the inclined plane of the screw. Meanwhile, the screw applies a large force through the short distance it is pushed. Screws are used most commonly as fasteners.

**Mechanical Advantage of Screws**

If you could unwind the inclined plane of a screw, you would see that the plane is very long and has a gentle slope. Recall that the longer an inclined plane is compared with its height, the greater its mechanical advantage. Similarly, the longer the spiral on a screw is and the closer together the threads are, the greater the screw’s mechanical advantage is. A jar lid is a screw that has a large mechanical advantage.

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**Homework**

**The Archimedes Screw** Have students research the invention of the Archimedes screw and the screw’s use through the centuries up to the present day. Have them describe as many applications of the screw as they can. **Logical**

**Zippers** Have pairs of students examine a zipper. Have them discuss how the slide on the zipper works and write two or three paragraphs describing the parts of the slide in terms of simple machines. **Verbal**

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**Using the Figure — General**

**Wedges** Use Figure 8 to help students understand that the output force from the wedge is applied perpendicularly to the input force. For instance, when you slide a doorstop under a door (a horizontal input force), the wedge pushes up on the door (a vertical output force).

**Activity — Basic**

**Screws** To help students better understand the concept of a screw, have them make a screw by cutting out the shape of an inclined plane. Have them color the sloping edge of the plane with a marker. Then, have them wrap the inclined plane around a pencil, starting with the tallest end of the plane. Point out that the colored edge of the inclined plane forms the thread of a screw. **Kinesthetic**

**Math**

**Mechanical Advantages of Screws** Provide three or four screws for each student. Have students calculate and compare the mechanical advantage for each screw by dividing the length of the inclined plane by the height of the screw. To measure the length of the screw threads, students should wrap a piece of string around five turns of the screw and then unwind and measure the string. By counting the total number of screw threads over the entire length of the screw, they can estimate the total length. This total length should be used for the length of the inclined plane. To determine the height, students should measure the screw from the top screw thread to the bottom. **Logical**

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**Activity — General**

**Materials**

*For Each Pair*
- cardboard
- magnifying lenses
- zippers, new or old

**Portfolio**

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Everyday Machines
With an adult, think of five simple or compound machines that you encounter each day. List them in your science journal, and indicate what type of machine each is. Include at least one compound machine and one machine that is part of your body.

**Compound Machines**

You are surrounded by machines. You even have machines in your body! But most of the machines in your world are **compound machines**, machines that are made of two or more simple machines. You have already seen one example of a compound machine: a block and tackle. A block and tackle consists of two or more pulleys.

**Figure 10** shows a common example of a compound machine. A can opener may seem simple, but it is actually three machines combined. It consists of a second-class lever, a wheel and axle, and a wedge. When you squeeze the handle, you are making use of a second-class lever. The blade of the can opener acts as a wedge as it cuts into the can’s top. The knob that you turn to open the can is a wheel and axle.

**Mechanical Efficiency of Compound Machines**

The mechanical efficiency of most compound machines is low. The efficiency is low because compound machines have more moving parts than simple machines do, thus there is more friction to overcome. Compound machines, such as automobiles and airplanes, can involve many simple machines. It is very important to reduce friction as much as possible, because too much friction can damage the simple machines that make up the compound machine. Friction can be lowered by using lubrication and other techniques.

**Compound machine** a machine made of more than one simple machine
Summary

- In a first-class lever, the fulcrum is between the force and the load. In a second-class lever, the load is between the force and the fulcrum. In a third-class lever, the force is between the fulcrum and the load.
- The mechanical advantage of an inclined plane is length divided by height. Wedges and screws are types of inclined planes.
- A wedge is a type of inclined plane. Its mechanical advantage is its length divided by its greatest thickness.
- The mechanical advantage of a wheel and axle is the radius of the wheel divided by the radius of the axle.
- Types of pulleys include fixed pulleys, movable pulleys, and block and tackles.
- Compound machines consist of two or more simple machines.
- Compound machines have low mechanical efficiencies because they have more moving parts and therefore more friction to overcome.

Using Key Terms
1. In your own words, write a definition for the term lever.
2. Use the following terms in the same sentence: inclined plane, wedge, and screw.

Understanding Key Ideas
3. Which class of lever always has a mechanical advantage of greater than 1?
   a. first-class
   b. second-class
   c. third-class
   d. None of the above
4. Give an example of each of the following simple machines: first-class lever, second-class lever, third-class lever, inclined plane, wedge, and screw.

Math Skills
5. A ramp is 0.5 m high and has a slope that is 4 m long. What is its mechanical advantage?
6. The radius of the wheel of a wheel and axle is 4 times the radius of the axle. What is the mechanical advantage of the wheel and axle?

Critical Thinking
7. Applying Concepts A third-class lever has a mechanical advantage of less than 1. Explain why it is useful for some tasks.

8. Making Inferences Which compound machine would you expect to have the lowest mechanical efficiency: a can opener or a pair of scissors? Explain your answer.

Interpreting Graphics
9. Indicate two simple machines being used in the picture below.

Answers to Section Review
1. Sample answer: A lever is a simple machine consisting of a bar that pivots at a fulcrum, acting to lift a load.
2. Sample answer: Wedges and screws are two special types of inclined planes.
3. b
4. Sample answer: first-class lever: seesaw; second-class lever: bottle opener; third-class lever: hammer; inclined plane: ramp; wedge: doorstop; screw: jar lid
5. MA = 4 m ÷ 0.5 m = 8
6. MA = 4 ÷ 1 = 4
7. A third-class lever increases the distance through which force is output.
8. Sample answer: a can opener; It is a compound machine that consists of three simple machines, whereas a pair of scissors is a compound machine that consists of two simple machines. The fewer the number of simple machines that make up a compound, the greater the mechanical efficiency of the compound machine. A compound machine consisting of few simple machines has fewer moving parts.
9. The door on its hinge is a lever (second-class); the knob is a wheel and axle.
A Powerful Workout

**Teacher’s Notes**

**Time Required**
One or two 45-minute class periods

**Lab Ratings**

![Easy](easy.png) ![Medium](medium.png) ![Hard](hard.png)

- Teacher Prep 📫
- Student Set-Up 📫
- Concept Level 📫
- Clean Up 📫

**Materials**
The materials listed for this lab are for the entire class or for smaller groups. Students in wheelchairs can use a ramp instead of a flight of stairs.

**Safety Caution**
Students who have asthma or any other respiratory problems should not perform this lab. Any student who becomes winded should sit down and take deep breaths. Caution students that this is not a race to see who can get the fastest time.

**Answer**
2. Sample answer: Climbing up a flight of stairs takes less than 100 W of power. This amount of energy doesn’t seem to be as much energy as a light bulb gives off.

**Lab Notes**
To help students calculate averages, set up a class data table on the board. The table should have four columns: “Student”; “Power S” (for power for slow walk); “Power Q” (for power for quick walk); and “Average” (each student’s average power). An individual’s average power is one-half of the sum of the power for a slow walk and the power for a quick walk. The class average power is all the individual averages together divided by the number of students in the class.
Now measure how many seconds it takes you to walk quickly up a flight of stairs. Be careful not to overexert yourself. This is not a race to see who can get the fastest time!

**Analyze the Results**

1. **Constructing Tables** Copy the Calculations Table below onto a separate sheet of paper.

<table>
<thead>
<tr>
<th>Weight (N)</th>
<th>Work (J)</th>
<th>Power for slow walk (W)</th>
<th>Power for quick walk (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. **Examining Data** Determine your weight in newtons, and record it in your Calculations Table. Your weight in newtons is your weight in pounds (lb) multiplied by 4.45 N/lb.

3. **Examining Data** Calculate and record your work done in climbing the stairs by using the following equation:

$$work = force \times distance$$

(Hint: If you are having trouble determining the force exerted, remember that force is measured in newtons.)

4. **Examining Data** Calculate and record your power output by using the following equation:

$$power = \frac{work}{time}$$

The unit for power is the watt (1 watt = 1 joule/second).

5. **Evaluating Methods** In step 3 of “Analyze the Results,” you were asked to calculate your work done in climbing the stairs. Why weren’t you asked to calculate your work for each trial (slow walk and quick walk)?

6. **Drawing Conclusions** Look at your hypothesis. Was your hypothesis correct? Now that you have measured your power, write a statement that describes how your power compares with that of a 100 W light bulb.

7. **Applying Conclusions** The work done to move one electron in a light bulb is very small. Write down two reasons why the power used is large. (Hint: How many electrons are in the filament of a light bulb? How did you use more power in trial 2?)

**Draw Conclusions**

5. The work is the same no matter how long it takes.

6. Sample answer: The power output in both the slow and quick walks was greater than the power of a 100 W light bulb. The original hypothesis was not correct.

7. The power of a light bulb is large because there is a huge number of electrons moving in the filament and the electrons are moving back and forth very quickly.

**Communicating Your Data**

Sample answer: The average power for the class was 250 W, so it would take two and a half 100 W bulbs to equal the power of one student.
ANSWERS

Using Key Terms
1. Sample answer: Work is a measure of the energy required to exert force over a distance. Power is a measure of the rate at which work is done.
2. Sample answer: A lever is a simple machine that consists of a bar that pivots on a fulcrum. An inclined plane is a simple machine that consists of a straight, slanted surface.
3. Sample answer: A wheel and axle is a simple machine that consists of two attached circular objects of different sizes. A pulley is a simple machine consisting of a grooved wheel that holds a rope or a cable.

Understanding Key Ideas
4. c
5. a
6. b
7. d
8. d
9. c
10. first-class levers and wedges

Using Key Terms
For each pair of terms, explain how the meanings of the terms differ.

1. work and power
2. lever and inclined plane
3. wheel and axle and pulley

Understanding Key Ideas
Work is being done when
a. you apply a force to an object.
b. an object is moving after you applied a force to it.
c. you exert a force that moves an object in the direction of the force.
d. you do something that is difficult.

What is the unit for work?
- joule
- joule per second
- newton
- watt

Which of the following is a simple machine?
- a bicycle
- a jar lid
- a pair of scissors
- a can opener

A machine can increase
a. distance by decreasing force.
b. force by decreasing distance.
c. neither distance nor force.
d. Either (a) or (b)

Sample answer: When you pick up a bag of groceries, the bag moves in the direction of the force. While you are holding the bag and walking, your forward motion is perpendicular to the upward force you are using to carry the bag, so you are not doing work on the bag.

Friction involved in the operation of the machine’s moving parts causes some of the input energy to be lost as heat.

For each class of lever, the mechanical advantage depends upon the placement of the fulcrum. If the fulcrum is closer to the load than to the input force, the lever has a mechanical advantage of greater than 1. If the fulcrum is exactly in the middle of the load and the input force, the mechanical advantage of the lever is 1. If the fulcrum is closer to the input force than to the load, the lever has a mechanical advantage of less than 1.

You and a friend together apply a force of 1,000 N to a car, which makes the car roll 10 m in 1 min and 40 s.

a. How much work did you and your friend do together?
b. What was the power output?

A lever allows a 35 N load to be lifted with a force of 7 N. What is the mechanical advantage of the lever?
Identifying Relationships  If the mechanical advantage of a certain machine is greater than 1, what does that tell you about the relationship between the input force and distance and output force and distance?

For each of the images below, identify the class of lever used and calculate the mechanical advantage of the lever.

23. second-class lever; \( \text{MA} = \frac{120 \text{ N}}{40 \text{ N}} = 3 \)
24. third-class lever; \( \text{MA} = \frac{4 \text{ N}}{20 \text{ N}} = 0.2 \)

Predicting Consequences  Why wouldn’t you want to reduce the friction involved in using a winding road?

Making Comparisons  How does the way that a wedge’s mechanical advantage is determined differ from the way that a screw’s mechanical advantage is determined?
Passage 1

The Great Pyramid, located in Giza, Egypt, covers an area the size of 7 city blocks and rises about 40 stories high. The Great Pyramid was built around 2600 BCE and took less than 30 years to complete. During this time, the Egyptians cut and moved more than 2 million stone blocks, most of which average 2,000 kg. The workers did not have cranes, bulldozers, or any other heavy-duty machines. What they did have were two simple machines—the inclined plane and the lever. Archeologists have found the remains of inclined planes, or ramps, made from mud, stone, and wood. The Egyptians pushed or pulled the blocks along ramps to raise the blocks to the proper height. Notches in many blocks indicate that huge levers were used as giant crowbars to lift and move the heavy blocks.

1. What is the main idea of the passage?
   A. Archeologists have found the remains of inclined planes near the pyramids.
   B. The Great Pyramid at Giza was built in less than 30 years.
   C. The Egyptians cut and moved more than 2 million stone blocks.
   D. The Egyptians used simple machines to build the Great Pyramid at Giza.

2. Which of the following is a fact stated in the passage?
   F. The Great Pyramid was made using more than 2 million stone blocks.
   G. Each of the stone blocks used to build the Great Pyramid was exactly 2,000 kg.
   H. Ancient Egyptians used cranes to build the Great Pyramid.
   I. The Great Pyramid at Giza has a mass of about 2 million kg.

Question 1: The information stated in answers A, B, and C is true, but those answers do not encompass the main idea of the passage as answer D does.

Passage 2

While riding a bicycle, you have probably experienced vibrations when the wheels of the bicycle hit bumps in the road. The force of the vibrations travels up through the frame to the rider. Slight vibrations can cause discomfort. Large ones can cause you to lose control of the bike and crash. Early bicycle designs made no attempt to dampen the shock of vibrations. Later designs used air-filled rubber tires and softer seats with springs to absorb some of the vibrations. Today’s bike designs provide a safer, more comfortable ride. Various new materials—titanium, for example—absorb shock better than traditional steel and aluminum do. More important, designers are putting a variety of shock absorbers—devices that absorb energy—into bike designs.

1. In the passage, what does the term shock mean?
   A. a medical emergency that can be caused by blood loss
   B. a dry material used in early bicycles
   C. a feeling of being stunned and surprised
   D. a jolt or impact

2. Which of the following is a fact stated in the passage?
   F. You have experienced vibrations while bicycle riding.
   G. Slight vibrations can cause severe discomfort.
   H. Titanium absorbs shock better than aluminum does.
   I. Today’s bike designs provide a more fashionable ride.

Question 1: A and C may be true alternative definitions of the word shock, but D states the meaning of the word given in the passage. This question tests students’ ability to read for meaning in context.
1. How does this lever make work easier?
   A by changing the direction of the force  
   B by increasing both force and distance  
   C by increasing force and decreasing distance  
   D by decreasing force and increasing distance

2. What would the mechanical advantage of this lever be?
   F less than 1  
   G 1  
   H greater than 1  
   I There is not enough information to determine the answer

3. What type of lever is the lever in the diagram?
   A a first-class lever  
   B a second-class lever  
   C a third-class lever  
   D There is not enough information to determine the answer

4. Which of the following items is the same type of lever as the lever in the diagram?
   F a seesaw  
   G a wheelbarrow  
   H a bottle opener  
   I an arm lifting a barbell

Question 1: The difference in sizes between the input force and output force arrows in the diagram indicates that the output force is smaller than the input force. This information alone is enough to point to answer D. You can tell by the directions of the arrows that the direction of the force is not changed.

Question 3: The unit of work and energy is joules, so B and D can be ruled out. A would be selected by a student mistakenly adding force and distance instead of multiplying them.
Math Activity

A conveyor belt on a kinetic sculpture lifts a ball to a point 0.8 m high. It exerts 0.05 N of force as it does so. How much work does the conveyor belt do on the ball?

Answer to Math Activity

\[ W = 0.05 \text{ N} \times 0.8 \text{ m} = 0.04 \text{ J} \]

Science, Technology, and Society

Kinetic Sculpture

The collection of tubes, tracks, balls, and blocks of wood shown in the photo is an audio-kinetic sculpture. A conveyor belt lifts the balls to a point high on the track, and the balls wind their way down as they are pulled by the force of gravity and pushed by various other forces. They twist through spirals, drop straight down tubes, and sometimes go up and around loops as if on a roller coaster. All this is made possible by the artist’s applications of principles of kinetic energy, the energy of motion.

Weird Science

Background

Advances in microtechnology have allowed scientists to achieve impressive results in many fields. For example, medical researchers are working on special pills equipped with sensors, tiny pumps, and drug reservoirs.

Other technological advances include microscopic filters and air turbines for controlling the temperature of microchip arrays. One team of scientists has created a molecular “on-off switch” that could be used to store information in computers.

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Answer to Language Arts Activity

Encourage creativity and scientific accuracy by providing students with a body atlas or similar reference work. Suggest the idea of specialized nanobots who can travel through only certain systems of the body (such as the circulatory, endocrine, or nervous system). What common problems might occur in that environment, and what could they do to help? For example, a nanobot inside a lung would see bronchial tubes, alveoli, and capillaries. The nanobot could break down contaminants in the air sacs, help fight off infections, or remove fluids in patients who have pneumonia.
Mike Hensler

The Surf Chair  Mike Hensler was a lifeguard at Daytona Beach, Florida, when he realized that it was next to impossible for someone in a wheelchair to come onto the beach. Although he had never invented a machine before, Hensler decided to build a wheelchair that could be driven across sand without getting stuck. He began spending many evenings in his driveway with a pile of lawn-chair parts, designing the chair by trial and error.

The result of Hensler’s efforts looks very different from a conventional wheelchair. With huge rubber wheels and a thick frame of white PVC pipe, the Surf Chair not only moves easily over sandy terrain but also is weather resistant and easy to clean. The newest models of the Surf Chair come with optional attachments, such as a variety of umbrellas, detachable armrests and footrests, and even places to attach fishing rods.

Social Studies Activity
List some simple and compound machines that are used as access devices for people who are disabled. Research how these machines came to be in common use.

Answer to Social Studies Activity
Wheelchairs consist of two wheels and axles. Wheelchair access ramps are inclined planes. Elevators (used instead of stairs by people who use wheelchairs) usually involve pulleys.